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ABSTRACT

The importance and intricacy of the solid wastes disposal problem and the need to deal with it effectively and economically led to the state-of-the-art survey covered by this report. The material presented here was compiled to be used by those in government and private industry who must make or implement decisions concerning the processing of solid wastes and the recovery and utilization of the wastes that are salvageable. The survey involved a detailed review of the pertinent technical and trade literature, personal interviews with individuals knowledgeable in appropriate fields, and questionnaires sent to the state health departments. For convenience, the report is divided into two major parts: Unit Operations and Processes and Major Waste Categories. The first part of the report is divided into six sections: Densification and Size Reduction, Separation, Sanitary Landfill and Open Dumping, Incineration, Chemical Processing, and Recovery and Utilization. This first part of the report also includes various regulations concerning solid waste disposal, discussion being based on responses to the questionnaires sent to the state health departments. The second part of the report, arranged alphabetically, covers all the major categories considered. The report concludes with a bibliography, which relates to both parts of the report. (JP)

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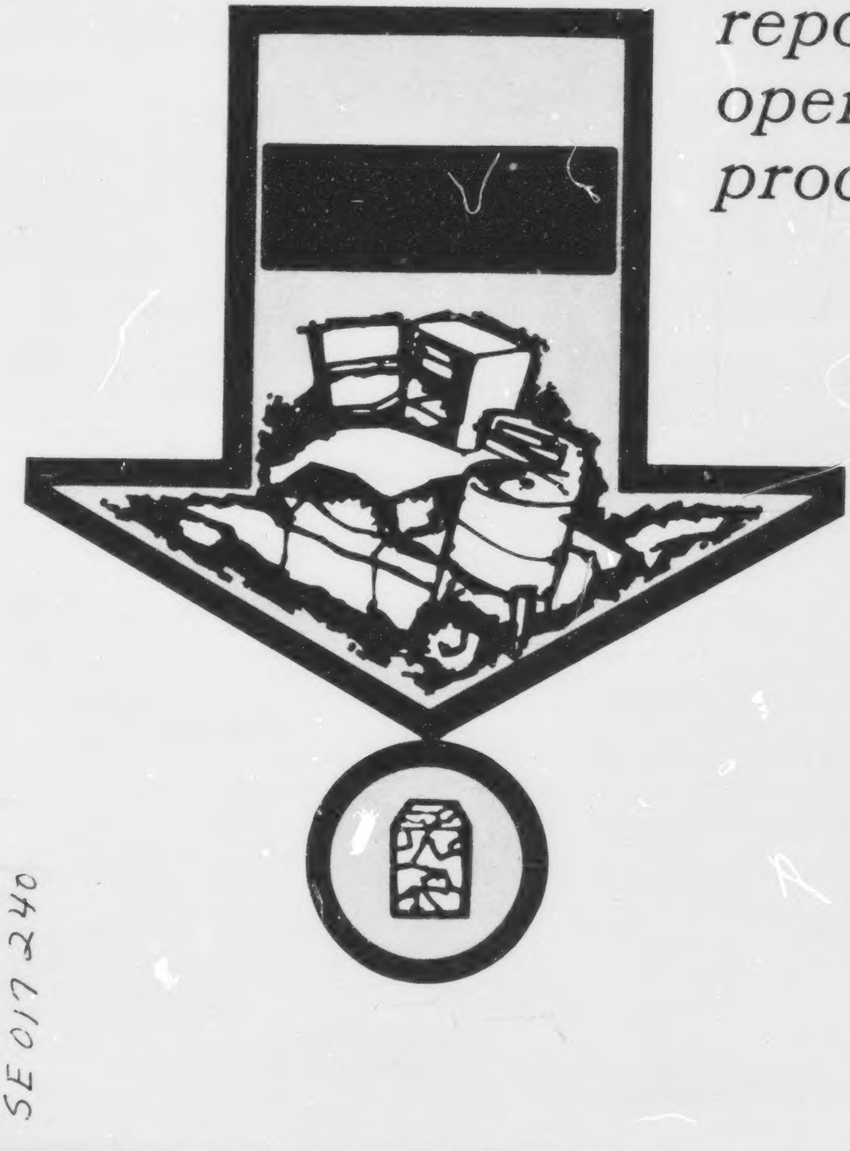
SOLID WASTE PROCESSING

A state-of-the-art report on unit operations and processes



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SOLID WASTE PROCESSING

A state-of-the-art report on unit operations and processes

This report (SW-4c) was prepared for the Bureau of Solid Waste Management
by RICHARD B. ENGDAHL
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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
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ENVIRONMENTAL CONTROL ADMINISTRATION
Bureau of Solid Waste Management
1969

Foreword

UNDER authority of the Solid Waste Disposal Act (Public Law 89–272) the Department of Health, Education, and Welfare has assumed major responsibilities for improving solid waste management practices in the United States. These responsibilities include conduct of research and demonstrations for developing or improving solid waste handling and disposal methods.

The Bureau of Solid Waste Management has sponsored the present study to provide a comprehensive reference to currently available solid waste unit operations and processes. Information is offered on the reliability of processes, performance data, economic factors, and range of commercially available equipment as an aid to researchers and those now engaged in solid waste management.

—RICHARD D. VAUGHAN, *Director,*
Bureau of Solid Waste Management.

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SOLID WASTE PROCESSING

A state-of-the-art report on unit operations and processes

MANY KINDS of solid wastes from a wide variety of sources must be processed daily for disposal in the United States. The great diversity in physical form and chemical content of the thousands of tons of solid wastes produced makes it extremely difficult to obtain an overall view of the disposal problem. Adding to the complexity of the situation, various industries and municipalities, influenced by a wide range of geographical, technical, and historical considerations, employ many different methods of treatment and combinations of equipment. Intimately associated with the disposal of wastes, moreover, is a problem of equal significance: the conservation of the nation's natural resources.

The importance and intricacy of the solid wastes disposal problem and the need to deal with it effectively and economically led to the state-of-the-art survey covered by this report. The material presented here was compiled to be used by those in government and private industry who must make or implement decisions concerning the processing of solid wastes and the recovery and utilization of the wastes that are salvageable. The survey involved a detailed review of the pertinent technical and trade literature, personal interviews with individuals knowledgeable in appropriate fields, and questionnaires sent to the State health departments.

For convenience, the report is divided into two major parts: *Unit Operations and Processes* and *Major Waste Categories*. Because overlap is considerable, cross-referencing is extensive to eliminate repetition. The first part of the report is divided into six sections: *Densification and Size Reduction, Separation, Sanitary Landfill and Open Dumping, Incineration, Chemical Processing,* and *Recovery and Utilization.* This first part of the report also includes various regulations concerning solid waste disposal, discussion being based on responses to the questionnaires sent to the State health departments. The second part of the report, arranged alphabetically, covers all the major waste categories considered. The report concludes with a bibliography, which relates to both parts of the report.

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Many people in government and industry cooperated with the Battelle survey team and contributed valuable information from their varied experiences for this compilation. Their assistance is gratefully acknowledged. The survey team, whose activities were coordinated by Richard B. Engdahl, included the following: David E. Bearint and Hobart A. Cress—densification and size reduction; Edward A. Beidler, Mary R. Fulmer, and George F. Sachsel—incineration, sanitary landfill, and open dumping, and chemical reduction processes; John R. Burke and Raymond W. Schatz—physical separation; and Howard C. Renken, John R. Burke, and Raymond W. Schatz—recovery and utilization. Editing and review were provided by Dolores Landreman.

Unit operations and processes

WHETHER one or a sequence of unit operations is required for solid waste processing depends on many factors, chief of which is the nature of the solid waste. In this survey, consideration of metallic wastes was limited primarily to nonferrous materials, because iron and steel scrap processing is already receiving considerable attention from both industrial and government organizations; automobile salvaging therefore, is not covered in the section on densification and size reduction. There are, however, many other waste disposal processes that require densification and size reduction. Consequently, this subject is discussed first.

DENSIFICATION AND SIZE REDUCTION*

Densification and size reduction are two unit processes employing equipment widely different in function, performance, and character.

Densification equipment significantly increases the weight of material occupying a given volume. A scrap-metal baling press is an excellent example. Densification or compacting equipment is not to be confused with pelletizing, or briquetting, types of equipment. Pelletizing equipment functions in a particle-size-enlargment capacity by agglomerating material and usually does not produce a significant reduction of the bulk volume.

Size-reduction equipment divides materials and reduces their individual or particle sizes. "Comminution" is a general term often applied to size-reduction processes. Some of the more familiar examples of size-reduction equipment are rock crushers, flour mills, and domestic sink-mounted garbage grinders.

Densification and size-reduction equipment is readily available in a wide range of types and capacities from many manufacturers. While much of this equipment was designed to handle materials other than solid wastes, most manufacturers are ready to modify existing equipment or to aid in the design and development of new equipment for solid waste disposal.

Densification and size-reduction equipment has been applied to most methods of solid waste disposal. Sanitary landfill operations employ various machines to increase the compaction and reduce the bulk volume of the refuse. Size-reduction equipment has been used in France on sanitary landfills for years and has recently been tried in North America. Size-reduction equipment has been used to reduce oversize and bulky wastes for incinerators. Shredding the entire feed to the conventional incinerator has been tried, but apparently with little success. Composting operations make extensive use of size-reduction equipment; however, most United States composting plants have been of the pilot or demonstration type; hence, full-scale and long-term operating experience with such equipment has been lacking. Disposal by salvage has accounted for an extremely small percentage of solid wastes. While densification and size-reduction equipment has been employed in salvage, applications have been few. An exception to this is found in England and Scotland, where direct salvage of solid wastes has been intensively practiced.

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*The highly developed secondary-materials industry is not discussed, nor is equipment to provide densification and size reduction of waterborne solid wastes.

In general, details on equipment were not found in the literature. Performance data, if mentioned, were usually limited to the horsepower rating of the driving motor, a rotor speed, or perhaps the average size of the comminuted material. Reliability was rarely mentioned. Economic factors were usually limited to estimated operating or maintenance costs. Capital costs were not discussed to any great extent in the literature surveyed. If more details are required, it will be necessary to initiate a more extensive program of correspondence and visits to manufacturers, operating sites, and consulting firms.

Pertinent information on manufacturers of densification equipment can be found in *Thomas Register of American Manufacturers*[7] under the headings "Presses" and "Balers." Another source is *The Waste Trade Directory.*[8]

Size-reduction equipment is widely used and is particularly important in the mineral and chemical process industries. Because of this broad interest, many articles were found dealing with the various aspects of size reduction. Various types of size-reduction equipment are reviewed in the *Chemical Engineers Handbook*[1] and *The Encylopedia of Chemical Process Equipment.*[2] A review article by Stern also contains a list of manufacturers and the types of equipment each supplies.[433] Other sources for manufacturers of size-reduction equipment are *Thomas Register* and the *Mechanical Engineers' Catalog.*[3] None of the equipment mentioned in these references was designed specifically for solid waste disposal.

PREPARATION FOR SANITARY LANDFILL

Most solid wastes have been disposed of in landfills. In fact, other disposal methods produce their own solid wastes that ultimately must find their way to a landfill of one type or another. Landfills have always been required and from all indications this will not change in the near future.

Following is a discussion covering the types of densification and size-reduction equipment that have been used when disposal is to a sanitary landfill. Some of the types to be discussed, such as packer-type collection trucks, could also be discussed in connection with incineration or other methods of disposal. However, since landfill is the most common method of disposal, they are included here.

Densification. As human populations grow, suitable sanitary landfill areas become more difficult to locate and more expensive. One obvious alternative is to make maximum use of available areas by reducing the bulk of the solid wastes. In most sanitary landfills, crawler or rubber-tired bulldozers have been used to work the fills. Depending on the character of the refuse, these machines can effect a compaction ratio of about 3 to 1. A machine designed specifically for sanitary landfill work has become available.[25] This is a 25-ton compactor-dozer employing lugged or gear-tooth-like wheels. The claim has been made that it quickly reduces packing crates and other large debris. It was reported that twice as much refuse can be placed in a given area without increasing the depth of fill as was formerly possible when a crawler tractor was used for compaction.

Another landfill-compaction device is a ballasted-drum type with lugs; it is pulled behind a dozer.[25] It also vibrates to improve compaction. A gasoline engine carried on the frame of the compactor supplies the energy of vibration.

Few references were found in the literature relative to compaction devices at sites of solid waste generation. A British publication mentioned a lever-operated unit intended to crush empty food, oil, or paint cans.[530] A somewhat different unit, apparently of United States manufacture, was said to crush tin cans, glass bottles, and plastic bottles and jugs.[545] The crushing occurred between continuous belts running at 100 feet per minute.

Vacuum-type leaf collectors seem to be increasingly common. The high velocities at which the leaves enter the collection box result in a significant amount of compaction. An article in *Public Works* described a 30-horsepower "Giant Vac" leaf loader that uses a 14-cubic-yard plywood collection box fitted to a 13-foot-long dump-body chassis.[91] The cost was given at $2,800, which included $300 for labor.

Compacting of solid wastes at the point of collection has been practiced in the United States since 1950 when packer-type refuse trucks were introduced. A review of some of the various types available from United States manufacturers can be found in *Refuse Collection Practice.*[63] A more recent review appears in *Machine Design.*[38] These trucks normally carry 10- to 30-cubic-yard bodies on a standard heavy-duty truck chassis. An exception to the practice of using a standard heavy-duty truck chassis is the Wesco Jet, a packer truck designed specifically for refuse collection. Depending on the character of the refuse, packer-type trucks can reduce the material to as little as one-third its original loose volume.[84] Prices for complete packer-type trucks ranged from $18,000 to over $30,000.[38]

European collection vehicles were reviewed by Rogus in Part II of an article in *Public Works.*[379] Four compaction systems are shown and described. One system employs two-stage compaction with a reciprocating ram followed by a swiveled compression plate that moves the refuse into the truck body. Two of the systems use helical screws to compact and move the refuse into the truck body. The fourth system is quite unique in that the truck body is a cylindrical drum fitted with an internal two-lead worm welded to the inner walls. The drum rotates at 3 to 4 rpm, crushing, compressing, and advancing the refuse toward the front of the drum.

As landfills are moved to more distant sites, it becomes more economical to employ central collection stations. At these stations, local collection trucks dump the refuse into large-capacity transfer semitrailers for hauling to the landfill site.[38] Local trucks dump the refuse into a hopper, where it is hydraulically compacted and pushed into the transfer trailer.

Rogus mentioned a similar type of centralized collection station used in Europe.[379] This appears to be the same system described in somewhat more detail in an English article.[543] This system is based on a 7-foot-diameter by 21-foot-long compaction cylinder fitted with a hydraulic ram. A 75-horsepower electric motor powers the hydraulic system. Refuse is loaded from the top through a hatch closed by a sliding door. When the compactor cylinder is full, the end is opened and the refuse is pushed into a matching circular container mounted on a transfer truck.

A recent development in solid waste compaction is a unique machine designed by the D and J Press Company.[38, 48, 525] The machine is 60 feet long by 23 feet wide and it weighs

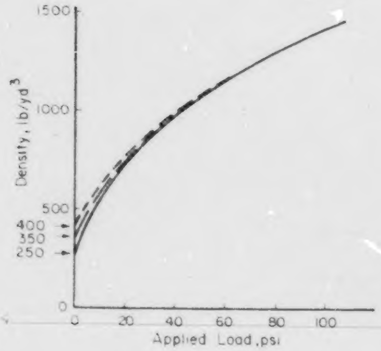


FIGURE 1. *Densification data. Refuse at Chandler, Arizona, test station, 1954.*

75 tons. Mounted on the machine are a wheel trencher and conveyor system, a tamper, a dozer blade, and a four-stage hydraulic press. Refuse is dumped onto a side apron, which transfers it to the compaction presses. The refuse is extruded from the machine via a 36- x 36-inch chute into a self-dug trench that can be up to 8½ feet deep. Fill dirt is placed over the compressed refuse and tamped. It was reported that the machine can handle large items such as old refrigerators and furniture. Compaction ratio was reported to vary between 10 to 1 and 20 to 1. Two 450-horsepower diesel engines supply the power under the control of two operators. Cost effectiveness and reliability apparently remain to be determined.

In a refuse compaction project at the King County Sanitary Operations, Seattle, Washington, the objective was to produce a solid that would neither decay nor emit harmful gases when used in a landfill. A proposed high-pressure (200-psi) compaction process was expected to reduce solid wastes to one-tenth of the original volume.

A glass-wool and shingle manufacturer in the United States was reported as using a transfer station compactor.[439] With use of the compactor, trailer runs from the plant to the disposal site were reported to have been reduced from 105 per week to only 10 per week.

An unsuccessful attempt at compacting refuse was made in Los Angeles County, California, where compacting and baling of municipal refuse was tried.[469, 470] Compressors and balers used were not entirely satisfactory and the bulldozers at the landfill sites had difficulty moving the bales around. Some work has also been done at the United States Public Health Service Test Station at Chandler, Arizona, on compression and baling of municipal refuse. The only published information found on this latter operation is a density-versus-applied-load curve (Figure 1).[84]

This curve appears to be in conflict with British data in a report describing a machine for compacting refuse in barges.[520] For hundreds of years London has been reclaiming areas by disposing of refuse in low-lying wastelands along the lower reaches of the Thames. Barges have been used to transport refuse from London wharves and to disposal sites. The low density of the refuse reaching the barges made for uneconomical light loads. To improve the situation, an overhead foot-type compacting machine was developed and installed at Walbrook Wharf. The British report describes this unique machine in some detail.

An interesting feature of the British report is a plot of percent reduction in volume versus compressive pressure for refuse of three initial densities. These data are referenced to the Institute of Public Cleansing and the work of W. A. Lewis.[259] When the Chandler, Arizona, data are replotted to a percent reduction in volume basis, rather than density, they differ from the British data (Figure 2). The curves for the 170- and 243-pounds-per-cubic-yard British refuse begins to flatten out with approximately a 70 percent reduction in volume at pressure of 6 to 8 pounds per square inch. The comparable 250-pounds-per-cubic-yard Chandler refuse curve has a very different shape and a 70 percent reduction in volume is not achieved until the pressures are 3 to 4 times those required with the British refuse. No doubt differences in refuse composition caused this variance.

The curves charted from the British data indicate where the point of diminishing returns is located with respect to the applied pressure. The British article concludes that pressures much over 6 to 8 pounds per square inch would be wasteful and uneconomical, since higher compression pressures would result in only small increases in the percent reduc

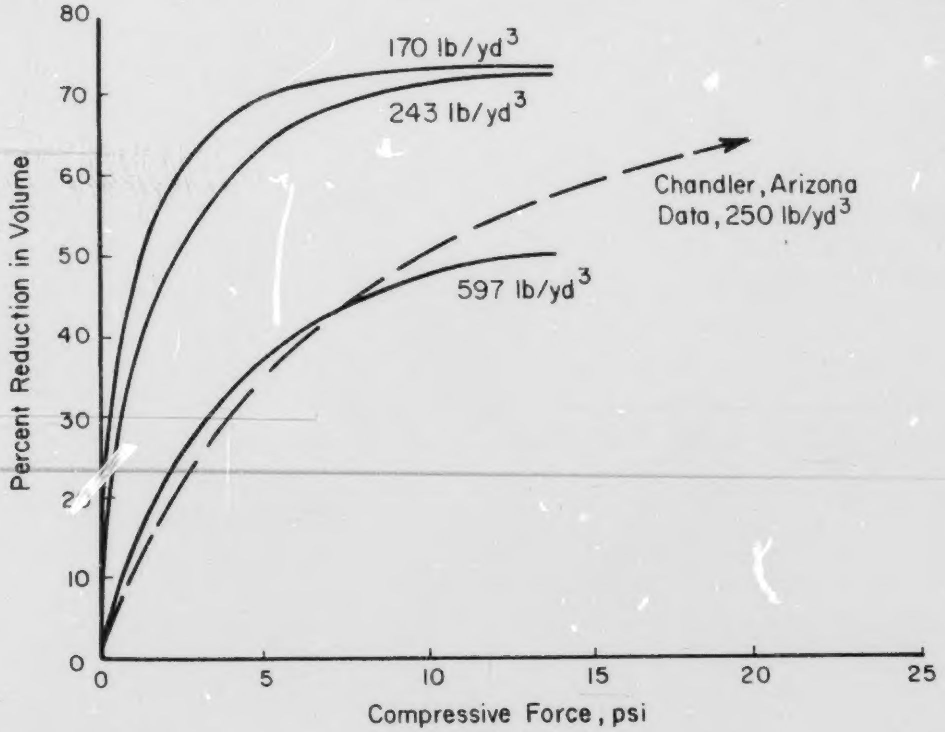


FIGURE 2. *Compaction data. Treatment of British refuse, 1963.*

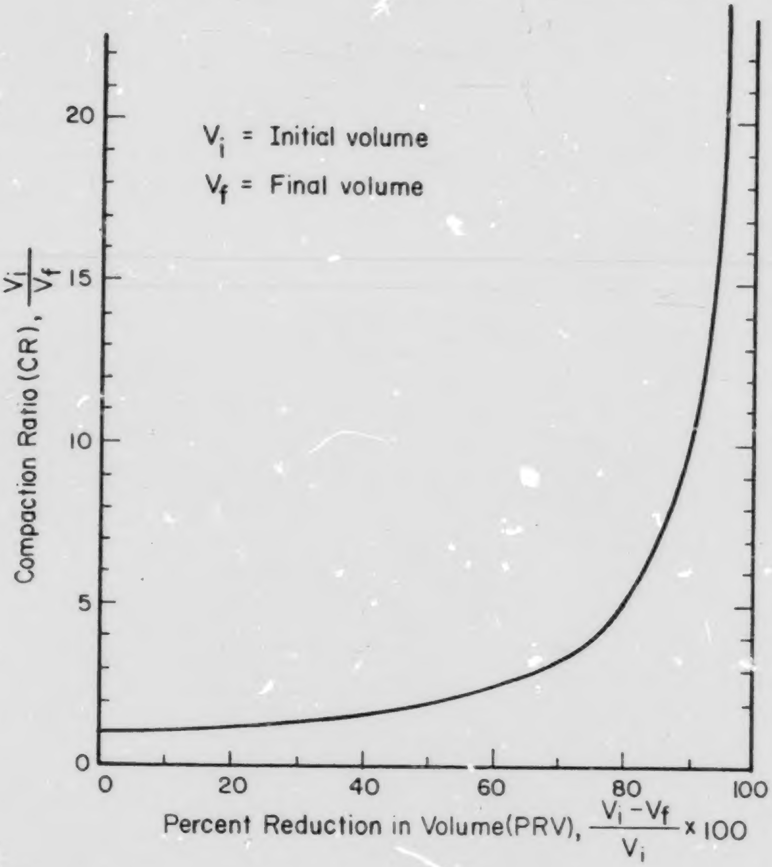
tion in volume. While this analysis applies to barges where total weight that can be carried by a barge is limited, it does not hold for landfills, where a much greater unit loading can be supported. For example, when compaction ratio is plotted against percent reduction in volume (Figure 3), this is not a straight-line function. Most important is the increase in the slope of the curve with increase in the percent reduction in volume. Thus, at the higher values of percent reduction in volume, small increases result in very large gains in the compaction ratio. For example, if collected refuse receives a 70 percent reduction in volume, the compaction ratio is 3.33. Gaining another 10 percent in the percent reduction in volume raises compaction to 5.0, a 50 percent gain over a compaction ratio of 3.33. Another 10 percent gain to 90 percent reduction in volume puts the compaction ratio at 10, or 300 percent above that obtainable with a 70 percent reduction in volume.

If the objective, then, is a reasonable tradeoff between compaction ratio and overall compactor costs, it might be approached on the basis of a plot of compaction ratio versus applied compressive pressure. The point of diminishing returns will then be where the slope of this curve "knees over" and becomes very nearly parallel to the pressure axis.

Since extensive compaction-ratio versus applied-pressure data did not appear to exist, it is recommended that they be accumulated. Such data would be of great value to users and designers of refuse compaction equipment. It would also be interesting to know how refuse might respond when the applied load is released.

Size reduction. Few published accounts were available on the size reduction of solid wastes for disposal by sanitary landfill. Some applications are rather unusual, at least compared with ordinary United States practice. The more unusual methods will be discussed first.

Upon first consideration, grinding municipal refuse before it is disposed of to a landfill might seem a needless and expensive proposition. It is not an unknown practice, however. A short article by Meyer briefly outlines the Heil-Gondard solid wastes reduction system based on a grinder developed in France.[206] The unique claim for this hammermill type grinder is that it will reject items that cannot be easily reduced. This is achieved first by hammer rotation that is opposite in direction to that in conventional hammermills and second by a rather tall vertical discharge chute built over the top of the mill. Ungrindable matter is said to be batted up into the



$$PRV = \left(1 - \frac{V_f}{V_i}\right) = \left(1 - \frac{1}{CR}\right)$$

or

$$CR = \frac{1}{\left(1 - \frac{PRV}{100}\right)}$$

PRV	CR
0%	1.00
10	1.11
20	1.25
30	1.43
40	1.67
50	2.00
60	2.50
70	3.33
80	5.0
90	10.0
95	20.0
100%	∞

FIGURE 3. *Compaction ratio versus percent reduction in volume.*

chute, where it is collected. Grinding and sorting would therefore be accomplished in one operation. Milled refuse with an original density of 375 pounds per cubic yard has had its density increased to about 1,050 pounds per cubic yard, for a compaction ratio of about 2.8 to 1. The milled refuse was claimed to be less attractive to pests.

This system was reported in use at a number of French landfills and at a large landfill at Montreal. The city of Madison, Wisconsin, recently received a demonstration grant to test the Gondard process. Rogus mentions that some French farmers have been applying screened, shredded, and pulverized refuse to their farmlands for many years.[379]

Another rather unusual size-reduction process was described in *Engineering*.[543] Relatively simple, it consists of a large rotating pulverizer drum into which refuse and water are introduced. On the drum inside wall are fixed plates that elevate the refuse through a fixed crushing cone as it is forced farther along the drum. The addition of water (up to 40 percent) helps fibrous materials, like paper, to break down. The resulting product has a peat-like appearance and is no longer dusty or offensive. Density increase is about 2.8 to 1, working with a feed density of about 286 pounds per cubic yard. Process time in the drum is about 1 hour.

The pulverizer described above is made by Vickers Seerdrum Limited, Surrey, England, and a plant is in operation at Wheatley, Oxfordshire, England. This particular drum is 8 feet in diameter by 29 feet in length and rotates at 11.5 rpm. Nominal capacity rating is 45 tons per day (TPD), although a continuous $7\frac{1}{2}$ tons per hour (TPH) throughput is possible. It is housed in a temporary 18- by 30-foot building, has a 50-kw power requirement, and is operated by two men. The plant is designed to be moveable to a new site. The British article quoted present "all-up costs" at $1.40 per long ton, which they said could conceivably drop to $0.84 per long ton with further development.

A slurry-type waste disposal system using size reduction has been described that combines a grinder, a slurry-transfer system, and a water extractor.[36, 63, 507, 544] Paper and food wastes are wet-ground to a pulp and the resulting slurry is pumped to an extractor where the water is removed and recirculated to the grinder. The semidry pulp is discharged to a can for final disposal. An 80-percent reduction in volume, or 5 to 1 compaction ratio, was reported as typical. Grinders were available from 18 to 72 inches in diameter with screen openings from $\frac{7}{16}$ to $\frac{5}{8}$ inch in diameter. Separators are available to remove metal, wood, plastics, glass, and other nonpulpable materials.[63] Where feed material was uncontaminated paper, the resulting uniform pulp was being reused by some paper mills, by manufacturers of roofing paper, and as paper maché for packing and decorative items.

Two applications of the system have been described in the literature, one in a new bank building,[544] where the system handles dining-room wastes, and the other at the Anaheim (California) Stadium.[543] The latter application is a $50,000 installation designed to reduce the 13,000 pounds of trash that accumulate during a typical ball game. Nominal capacity of this unit is 2,000 pounds per hour.

Brush chippers represent another type of on-site solid waste size-reduction equipment that has been coming into wider use. These brush chippers are smaller versions of large wood hogs, which are simply hammermills with knife-like hammers. They were available from many manufacturers. Reduction in volume is about 80 percent. Chippers can be unit-towed behind a truck[518] or mounted with a packer on a truck chassis.[452]

Paperboard-box shredders are yet another method for reducing bulk volume at the site of solid waste generation. Although box shredders have been rather common and the equipment has been readily available, no technical literature was found on the subject, although general advertising pamphlets were available.

PREPARATION FOR INCINERATION

The literature describes applications of both densification and size-reduction equipment to incinerators although the majority of these applications involve size-reduction equipment.

Densification. Densification equipment is not normally associated with the incineration of solid wastes. The only description approaching a densification process was found in Rogus' review on Western European practice, in which the making of briquettes from refuse was mentioned.[379] Experimental work has been done in England and Switzerland, and more was being planned. The process involved sorting the refuse to remove noncombustibles, grinding for greater uniformity, drying to bring moisture content below 10 percent, and, finally, extruding a 2- to 3-inch-diameter briquette. Calorific value was reported to be in the range of 8,000 to 10,000 Btu per pound. One drawback seemed to be that 6 tons of normal domestic refuse produce 1 ton briquettes and the remaining 5 tons had to be disposed of by other means.

Metal recovery from incinerator residue is a common practice. In Europe, some plants bale this for subsequent sale. In the U.S. literature this aspect of densification was barely mentioned.

Size reduction. With a few exceptions, the present application of size-reduction equipment to municipal incinerators has been limited to the reduction of bulky or oversized items in the United States as well as in Europe. Shredding of the entire feed has been tried and was apparently in very limited use recently. Its use has been advocated for future incinerator applications by Meyer.[illegible]

Bulky or oversized refuse is the combustible solid waste that cannot, for several practical reasons, be directly charged to conventional municipal incinerators. This waste may be too large for direct charging, it may burn too slowly, or it may contain noncombustible portions that interfere with the incinerator grates or residue-discharge system. Typical examples are construction and demolition wastes, furniture, mattresses, and tree stumps.

A hammermill installation at the Gansvoort Street Incinerator in New York City was described in 1961.[533] A test run indicated that it would reduce demolition wastes (primarily wooden beams). Nothing further was found in the literature, however, and it was learned from other sources that the mill was soon taken out of service.

A more recent news item indicates that the problem of satisfactorily reducing bulky solid wastes still remains to be solved.[10] The news item also mentioned that the New York City Sanitation and Air Pollution Control Departments were working together to evaluate the use of shredders for reducing oversize burnable wastes.

Rogus, in articles on European incinerators, stated that most of the incinerators investigated also handled large, oversize materials.[377, 378] These materials were segregated and moved by crane to specially designed impact crushers or multiple-type shears. After being reduced, the material was chuted to the common receiving pit for processing with the normal refuse.

Fichtner, Maurer, and Muller reported that a Hazemag impact crusher was in use at the Stuttgart incineration plant to reduce bulky incoming refuse.[134] The article did not discuss the crusher further.

Kaiser proposed the burning of bulky items on a refractory floor in a special bulk-refuse furnace, thus eliminating the need for hammermills, which have sometimes operated with only indifferent results.[219, 362]

A wood chipper in use at a Fitchburg, Massachusetts, incinerator in 1955[517] was used to reduce Christmas trees, banana stalks, and demolition wood wastes. Prior to use of the chipper, tree sap had caused grate problems by sticking and jamming the mechanical components.

Although shredding of the entire refuse feed to an incinerator has not been common practice, it was tried in the early 1950's at the Betts Avenue Incinerator in New York City.[362, 505, 546] Four hammermills, each having a 30-TPH nominal capacity, were designed into the plant. The shredding operation was admittedly experimental. The objective was to provide operating data and experience that would determine whether a more homogeneous feed justified the additional operating, maintenance, and capital costs associated with the shredding equipment. It is interesting to note that shredders were not incorporated in subsequent New York City incinerator plants for treating the entire feed to the incinerator.

Meyer, describing the Heil-Gondard hammermill, mentioned the first commercial installation of this mill in an incinerator would be made by a French firm in St. Quentin.[295] A Swiss incinerator was also described in which the refuse was milled, sewage sludges were added, and the wet mixture dried and then burned. The heat for drying was derived from the previously dried refuse-sludge fuel mixture.

Meyer and Leibman each claimed greatly improved incinerator operation and savings on cost and size of other components from the use of shredders.[295, 358] Explosive hazards from containers of volatile liquids and aerosal cans were eliminated. Also, feed rates to the incinerator could be more uniform and easier to control, but no published data were found on these effects.

The use of size-reduction equipment in shredding the entire feed for an incinerator has not been a great success in the past. On the basis of the two articles referenced above, it appears that hammermills have been unable to handle unsegregated refuse at an acceptable level of reliability and maintenance.[295, 358]

PREPARATION FOR COMPOSTING

Densification equipment is not normally associated with composting. There is mention in the literature of pelletizing compost; however, this actually functions as a particle-size-enlargement process. Baling of salvage materials, such as paper, cardboard, and metals, has been practiced at some compost plants.

With respect to size-reduction equipment, composting operations have represented what is perhaps the most extensive application of such equipment in the field of solid waste disposal. A size-reduction operation is required at one point or another in virtually all of the many types of composting processes.

The amount of size reduction practiced during composting operations can vary, depending on the type of composting process and the intended use of the resulting product. A few operations compost the refuse in the "as-collected" condition, with no size reduction at all. Other processes require some size reduction of the incoming material, sometimes in a slow-moving rasping machine. Still other composting processes require average particle sizes below an inch. This requirement has often been met by two-stage grinding in hammermills. If the final product is to be acceptable for home gardening and horticultural purposes, it must be of uniform character and free of rocks, glass shards, large metal fragments, and other undesirable, potentially injurious components. Screening, ballistic separation, and final reduction in a roll crusher or hammermill usually accomplish this before the compost is bagged for distribution and sale. Other uses for compost usually do not require such stringent control on the character of the product, so that a reduced degree of size reduction or none at all, is employed.

As far as the size-reduction process is concerned, all composting plants in the United States appear to differ from each other, even others of the same type, possibly because most plants are demonstration or pilot projects. Rarely do two plants use the same size-reduction equipment, in the same manner, and on the same type of solid waste. In view of this, size-reduction equipment for composting will be discussed in six broad categories: hammermills, flail mills, vertical-axis rasps, drum rasps, roll crushers, and pulpers.

Hammermills. Hammermills represent the broadest category and cover all types of high-speed crushers, grinders, chippers, or shredders that employ pivoted or fixed hammers or cutters. These machines usually have a simple horizontal rotor, but twin rotors and a vertical rotor orientation were also available. However, the literature provided very few details.

Part of the United States Public Health Service research project initiated in 1953 at Chandler, Arizona, was the development, construction, and operation of a 70-tons-per-week (TPW) experimental composting plant.[34] During the operation of this pilot facility, substantial information was reportedly gathered on the cost of refuse grinding, but further details were not given in the project report, and attempts to obtain more information were unsuccessful.

A 1956 report of the American Society of Civil Engineers presents cost information on 12 different compost methods.[304] The pilot-plant operation at San Diego which is described was on a rather small scale, initial pile weights running between 5,340 and 8,340 pounds. According to the report, the cost figures do not include the expense of supervision, plant investment, and other overhead, but do reflect the expense of grinding, cleanup, power, turning, wetting, fly control, additive materials, and screening when utilized. Operating costs ranged from $1.56 per ton for an unground, no-additive, compost to a high of $20.48 per ton for a coarse grind with a straw additive. The average cost was $12.79 per ton. When grinding was employed, its costs accounted for 30 to over 60 percent of the total cost per ton. The size-reduction unit was simply identified as a garbage grinder and no further information was supplied.

A full-scale operation involving the Dano process was initiated in 1956 at Sacramento.[155] The picked refuse, before entering the Dano biostabilizer drum, was ground in a 25-ton Pennsylvania hammermill. The mill was considered oversized for the job, and breakdowns were reported as being infrequent. Major maintenance consisted of removing, resurfacing, and replacing the hammers. This took 3 to 4 hours to accomplish and was done every 3 months. Another hammermill reduced the compost leaving the biostabilizer. This plant was shut down in 1963.

A 1963 review of European composting equipment mentions hammermills and rasping machines as the two types of refuse grinders used in Europe.[465] Most of the hammermills were of the single-rotor, swing-hammer, high-speed type. Some recent hammermills, however, have employed two rotors running at different speeds—for example 1,500 and 3,000 rpm.[98]

Another 1963 review covers a vertical-shaft hammermill developed by Tollemache Composting Systems, Limited, London, England.[546] While any size is possible, the one described is a 150-horsepower unit rated at 12 TPH. The unit features mobility and ballistic separation of ungrindables. Maintenance was reported to be less than $0.25 per ton of refuse processed.

The van Maanen system of composting makes no attempt at size reduction until decomposition is complete[447] Raw, incoming refuse is sprinkled with water and placed in windrows. In 2 or 3 months, the windrows are turned, and in 4 to 8 months the compost is mature. It is then screened, sorted, and finally passed through a hammermill. This economical system of composting was in use in The Netherlands, where the compost was applied to arable farmland to maintain and improve the physical characteristics of the soil. The article mentions hammermills but does not go into any further details.

The Heil-Gondard hammermill mentioned previously has also been applied to composting. In Haarlam, Holland, a plant used such a mill,[208] as did several in Spain.[60] The Spanish installations were at Pamplona (60 TPD), Zaragoza (120 TPD), Cadiz (40 to 50 TPD), and Madrid (200 TPD). Several others were being built or were being planned. The Gondard hammermills are rated in the 10- to 14-TPH range and reduce the refuse to a nominal size of about an inch.

See also: Zircaloy.

Flail mills. A composting system under development for a number of years in the United States makes use of flail-type size-reduction equipment.[85, 149, 287, 288, 521] This is a horizontal, single-rotor unit with a studded shell and hammers attached to the rotor by means of chains. Replacements of hammers and chains were reported to be relatively easy, while new shell studs, due to the unique design, were moved into position by simple rotation. This unit was designed specifically for the reduction of municipal solid wastes when shock loads and abrasion predominate. The flail reducer was used at two points in the composting process—on the incoming refuse and during a regrind midway through the digestion phase.

Vertical-axis rasps. Another approach to reducing operation and maintenance costs of solid waste size reduction is to use the rasping machine. The vertical-axis rasp was developed in The Netherlands.[97, 161, 466] It consists of a vertical axle carrying eight horizontal arms hinged to rotate upward. The axle rotates at about 15 to 25 rpm, sweeping the arms over the upper bottom, or grinding floor, of the unit. The grinding floor is made up of alternate plate sections containing either perforations or welded extensions. The material to be reduced is dropped into the unit where the rotating arms move it into contact with the protruding rasping pins. The material that is sufficiently reduced then drops through the holes in the following plate.

Rasping units are about 16 feet in diameter by about 7 feet in height. Capacities are in the 5- to 15-TPH range, depending primarily on the size of the holes in the perforated plates. Compared to a hammermill, a rasping unit has a higher first cost and is larger. The advantages of a rasp are in reduced power requirements and much less maintenance.

Drum rasps. Another type of rasping unit is the drum type. In the United States, this has been developed in the form of a unit known as a pulverator.[149, 287, 288, 521] This is a 6-foot-diameter by 16-foot-long inclined drum covered on the inside wall with triangular steel plates. This unit has been used to tear open bags, break up large agglomerations, and mix the incoming refuse before it is sent to the flail-type hammermills.

The Dano grinder, Egsetor unit, is a drum-type rasp.[161] In addition to internal rasping bars, this unit has a screen within the outer drum. Material falling through the screen is passed to the grinders or directly to compost piles. It rotates at 12 rpm and was reported to require about 6 kw per ton of refuse. The Dano biostabilizer also has a mechanical rasping action on material moving through the rotating drum.

Roll crushers. A crusher that seemed to have had limited application to composting operations is the roller type. Only one reference to its use was found in the literature.[435] This article briefly describes a smooth, double-roll crusher in use at Almelo, in The Netherlands. It was reported that this crusher was used to reduce glass shards and other brittle materials in mature compost before it leaves the plant.

Pulpers. A final type of size-reduction unit employed with composting operations is the unique pulper in use at Altoona, Pennsylvania.[380] This wet pulper consists of a 6-foot-diameter steel bowl with a rotatable steel plate mounted in the bottom. During operation, the bowl is first partially filled with water, which is followed by the solid material to be composted. The steel plate rotates at 650 rpm and in 5 minutes produces a slurry containing about 5 percent solids. The slurry is then discharged through a screen to a screw-type dewatering press where the moisture content is reduced to 75 to 80 percent. A second press follows, which reduces the moisture content to 50 to 60 percent. The pulp is then discharged to the digester.

PREPARATION FOR SALVAGE

The last method of solid waste disposal to be considered in this section of the report is disposal by salvage. For the purposes of this study, salvage is intended to cover the applications of densification and size-reduction equipment to the direct recovery, processing, and use of materials taken from nonferrous, mixed solid wastes, such as those collected by municipalities. This discussion does not cover the wide range of equipment in everyday use in the existing and already highly developed automobile scrap and secondary-materials industries.

The literature survey indicated that disposal of solid wastes by salvage was limited. This was particularly true in North America, and, with two exceptions, it seemed as limited in Western Europe. Only three articles were found with more than passing mention to salvage as a means of solid waste disposal. Several of the articles found on composting do mention that salvage operations were being, or could be, applied to the system. None, however, offered details describing existing or proposed densification or size-reduction equipment.

In the United States, large-scale disposal of municipal-type solid wastes by salvage seemed to be limited to the unique system existing in Los Angeles, California. An article on this subject appeared in a 1963 issue of *Compost*

Science.[384] Prior to 1957, residents of Los Angeles separated their solid wastes into garbage, combustible refuse, and noncombustible refuse. The garbage was fed to swine and the combustibles were burned in backyard incinerators. The resulting incinerator residue was mixed in with the noncombustibles, which were collected and disposed of through the salvage industry. Since 1957 and the passing of air pollution laws, Los Angeles no longer permits backyard incineration. Garbage not ground and flushed to sewers was being put in with combustibles and disposed of to municipal incinerators or landfills. Noncombustibles were still being separated and disposed of by a contractor.

The prime material salvaged from Los Angeles' noncombustible refuse was tin cans, although scrap iron, cast iron, and nonferrous metals were also removed. The cans were being used in a process that precipitated copper from leaching solutions at copper-refining operations. After magnetic separation and processing to remove extraneous materials (food wastes, labels, paint, etc.), the tin cans were shredded into "premt". The can shredder was described as a special one developed to provide an ideal product for the precipitation of copper. Further details on the shredder were not given.

Apparently, the only other large-scale direct salvaging operation in North America was an installation outside Montreal, Canada.[554] The prime purpose of this plant was actually bulk reduction of municipal solid wastes, not salvage. The refuse moved from the receiving pits to hoppers and from there to conveyor belts, where it passed through a sorting room. Apparently, all sorting was done by hand labor, the workers dropping the salvageable material into collection boxes via chutes. Balable material was taken to one of two baling presses.

It was reported that when salvaging was in operation, bulk was reduced by 40 percent and weight by 25 percent, based on the incoming refuse. All material not salvaged passed to one of two Gondard hammermills.[298] From the mills, the refuse went to a stationary packer which loaded 35-cubic-yard containers. These were, in turn, picked up by a special truck and hauled to a landfill. Maintenance costs on the hammermills were estimated to be less than $0.57 per ton, with hammers being replaced every 1,000 tons.

Salvage as a disposal method in European countries was discussed in Rogus' series of articles on Western European practices. Rogus stated that, with the exceptions of England and Scotland, direct salvaging was not practiced extensively in Western Europe. He went on to point out that English salvage plants did employ highly developed and efficient machinery, including presses and baling machines. More extensive information was not given. Rogus concluded that the trend was away from salvaging because of the effects of high labor costs, modern technology, and development of synthetic materials. He further reasoned that new end uses would have to be found for salvageable material before this method of disposal could be considered competitive.[379]

See also: Recovery and Utilization; Individual Waste Types.

SEPARATION

Physical methods of separation may be applied to solid wastes by utilizing existing or induced differences in the physical properties of the materials being separated. The separation may result in the production of a useful product or in easier disposal of one or more fractions of the waste.

The materials defined as solid waste, "garbage, refuse, and other discarded solid materials", have not been subject to separation treatment other than the simplest type such as handsorting, because until recently there has been no need for separation to permit easier disposal. It is quite probable that with increased emphasis on this subject, more of the available techniques will find application.

A few cost data are presented here, but they should be used only as a guide because costs may vary markedly in different applications of the same process. In addition, available cost data are at least several years old, and with the changing economic picture can no longer be considered firm.

A large number of companies manufacture various designs of the equipment described. A typical reference source to manufacturers is the *Mining Guidebook*, which is published yearly.[6] Similar guidebooks are published by the trade journals that serve the various industries.

The major differences in physical properties by which solid wastes may be separated are as follows: color, luster; size; shape; tenacity, brittleness, or friability; structure and fracture, texture; surface characteristics; specific gravity; magnetic susceptibility; electrical conductivity; radioactivity; and decrepitation.

In many instances it is possible to change physical properties by such means as chemical alteration of surface characteristics, drying to improve electrical conductivity, oxidation to affect magnetic properties, and application of vacuum to porous materials to change specific gravity. The unit processes that are described in the following paragraphs are: (1) Processes incidental to separation, including size reduction (crushing and grinding), sizing (screening and classification), and fluid–solid separation (thickening, filtration, dust collection); (2) sorting; (3) washing and scrubbing; (4) gravity concentration; (5) magnetic separation; (6) electrical separation; (7) flotation.

See also: Diamond Grinding Wheel Dust; Refractory; Wastepaper.

PROCESSES INCIDENTAL TO SEPARATION

Size reduction. Before separation can be accomplished, the materials to be separated must be liberated and sufficiently reduced in size for application of separation techniques. Size reduction and sizing, consequently, may play an important part in most separation processes. Because the materials that constitute solid wastes may range from the hard-rock types to vegetable, fibrous, and even fleshy types, a wide range of crushing and grinding equipment is required. In one instance, equipment peculiar to the mineral industry may be quite satisfactory, yet in another instance the same machinery might be unusable. For treating some materials, new equipment might have to be designed, as has recently been the case for the processing of automobile bodies. In general, it might be concluded that with the various types of crushing and grinding equipment available, units can be procured for almost any type of size-reduction operation.

If the material to be treated is hard and abrasive yet will fracture under impact or can be abraded, equipment used in the mineral industry, such as jaw and gyratory crushers, rolls, ball and rod mills, and hammermills, is applicable. For materials that deform under pressure, knife-blade or cutting-type hammermills, shredders, chippers, etc., are applicable.

If extremely fine grinding is required, particularly for materials utilization rather than liberation, such

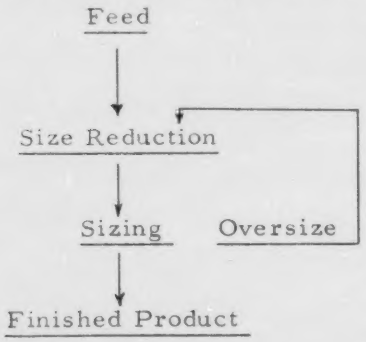


FIGURE 4. *Typical size-reduction flow sheet.*

devices as vibratory ball mills and fluid-energy mills are available.

High-speed agitators or macerators may be utilized in some operations. In the utilization of waste paper, for example, liberation of ink from newsprint is done in a Hydrapulper, a high-speed agitator manufactured by the Black Clawson Company. A similar machine is the Wet Pulper manufactured by The French Oil Mill Company.

The use of several different types of crushing and grinding equipment is quite common. This has led to the development of such terms as primary or coarse crushing, secondary or intermediate crushing, fine crushing, and grinding, the distinctions between the operations being purely arbitrary. What may be a fine-crushing unit in one treatment may be a coarse-crushing unit in another.

Size-reduction equipment is usually quite massive. It is generally available in unit sizes varying from laboratory devices to mammoth units that require several-thousand-horsepower motors to operate.

The crushing surfaces are usually replaceable, thus, the life of the equipment is long. A 30- or 40-year life for well-designed and well-constructed units is not unusual.

The cost of size reduction in the coarse sizes is low—a few cents per ton, whereas in fine grinding it may run from $0.50 to $1.00 per ton. The primary cost item is power, maintenance being next. Labor cost is usually low unless the operation requires attendance to permit uniform feeding.

Sizing. In many operations sizing is concurrent with size reduction. The function of sizing is to limit the size of materials going to the next unit process—either further crushing or separation—as may be seen from a typical size-reduction-sizing flow sheet (Figure 4).

A combination of size reduction and sizing may also constitute a unit separation process when one or more of the constituents grinds more easily than another, thus producing a finished coarse fraction and a finished fine fraction. The treatment of aluminum dross is an example of this. The slag component breaks up readily, whereas the malleable aluminum does not. After crushing and screening, a coarse oversize, high in aluminum, and a fine undersize, high in slag, are produced.

Sizing may be done either wet or dry with screens or classifiers. Screens may be either stationary or moving, flat or inclined. Screen movement may be brought about by shaking, rotation, or vibration. Screen openings may vary from several inches or more in the coarse grizzly screens, the screen being constructed of railroad rails, to fine screens with openings 0.0015 inch in diameter (400 mesh), or bolting cloths with even finer openings. The openings may be round, square, rectangular, or slotted. Round, flat, and wedge-shaped wires may be used.

Classification generally takes the place of screening in the fine-size ranges. Wet classifiers of the helical-spiral type, the rake type, or the cyclone type are very common. Air classification likewise employs cyclones or mechanically driven centrifugal separators

The mechanism of sizing by screens is dependent simply on particle size versus size of opening, whereas in classification, settling rates determine the size of the separation. Settling rates are a function of size, shape, and specific gravity. Of two particles of the same size and shape, the one with the higher specific gravity will settle first. Consequently, in a classifier closed-circuit grinding operation, it is not unusual to find a concentration of higher specific-gravity material in the finer size fractions of the classifier product.

Particle shape affects sizing. Acicular (needle-like) and platy materials are much more difficult to size than equidimensional particles.

Probably one of the most significant advances in screening has been the introduction of the sieve bend. This is a stationary, concave screen made up of wedge wire bar screen at right angles to the material flow. Because of the angle at which the material contacts the screen, a wider screen opening can be used for a given size of separation. This increases the commercial field of application down to as fine as 100 mesh for high capacity per unit of screen area and minimizes blinding, the filling of screen openings by particles of the same size.

The greatest improvement in classification has probably been the introduction of the cyclone, both wet and dry.

Sizing is a relatively simple and inexpensive operation. Horsepower requirements have been low. Screen cloth replacement has been the major maintenance item in screening, whereas in classification wear of flights or spirals has been the major cost item. Rubber, ceramic, or other linings keep maintenance low in cyclones or centrifugal separators.

See also: Bagasse; Brewing, Distilling, Fermenting Wastes; Wastepaper; Wood Wastes; Zircaloy.

Fluid-solid separation. In most processes of physical separation of materials, some method must be employed for the removal of a solid fraction from a fluid medium.

For liquid-solid separation, such devices as thickeners, filters, centrifuges, cyclones, classifiers, and even screens have commonly been used for this purpose. Crude liquid-solid separation can be effected by stationary drainage on a sloping floor or in tanks or bins with provision for liquid removal at the bottom.

Gaseous-solid separations (dust collection) may be accomplished in settling chambers, baffle-type collectors, centrifugal collectors (cyclones), mechanical-type collectors, gas filters, bag houses, spray washers, and electrical precipitators.

In many of these devices, separation of the fluid and solid is simply a matter of settling by means of thickeners, settling chambers, bag houses, etc. In other devices, such as filters, the fluid of the fluid-solid stream is forced through a membrane (filter cloth) that retains the solids on its surface.

Thickening followed by filtration has probably been the most common procedure used in liquid-solid separation. With solids that filter reasonably well, vacuum filters of either the drum or the leaf type can be used. For more difficult filtration problems, pressure filtration in plate and frame or pressure-tank-type units can be employed. In vacuum filtration, the pressure differential has been limited to atmospheric pressure (14.5 psi at sea level), whereas with pressure filters, pressures of 50 to 60 psi have not been unusual.

The cost of vacuum filtration has varied widely, $0.10 to $0.20 per ton being the average. Thickening costs have been very low, as in the cost of dewatering by screening, cycloning, and similar methods.

The cost of electrostatic precipitation may vary from as little as $0.02 to as much as $0.30 per 100,000 cubic feet of gas treated, depending on the solids content, the solids size, and the efficiency of removal required.

Drying may be required in some instances to reduce the moisture content to an acceptable figure. Rotary kilns and spray driers have been two commonly used types. Heated floors and vertical towers have also been employed. The primary cost in drying has been that of fuel, and the fuel requirements are virtually a direct function of the moisture content.

SORTING

Both hand sorting and mechanical sorting have been employed, with much of the mechanical sorting equipment being associated with the waste-paper-salvage industry.

Hand sorting. Hand sorting of material is probably the oldest unit process of physical separation. To a degree, sorting operations are performed in virtually every manufacturing industry, if for no other reason than to reject imperfect items.

The material to be sorted must have a readily distinguishable property such as color, luster, shape, size, general appearance, or radioactivity. It should be the minor constituent and of such size and weight that it can readily be moved.

In some basic industries such as mining, hand sorting has been eliminated because of the increasing cost of labor, and, to a lesser degree, the development of mechanical methods.

Much of the solid waste generated by an urban population could be hand sorted at its source to minimize subsequent disposal problems. (This has been done in Los Angeles for many years.) Separation of household and similar waste into such categories as paper, glass, metal (cans, etc.), and garbage, would impose no particular problem on the individual household and would be done at no cost to the overall waste-disposal program. The sorted items could then be channelled to their proper disposal point (e.g., reuse, incineration).

Hand sorting of contractors' construction waste into its various components should facilitate waste disposal without adding a significant cost to construction.

A very effective method of hand sorting is to use a picking belt about 24 inches wide if there are sorters only on one side, or 36 to 48 inches wide if there are sorters on both sides. Sorters are usually about 5 feet apart. A belt speed of 30 to 40 feet per minute has been the average. Chutes or belts below the picking belt are provided to handle the picked fraction. The material on the belt should be clean, not more than one unit deep, and well illuminated. Benches or tables can also be used, particularly where deposition of a uniform layer on a belt is not feasible, as in the case of wastepaper-type materials. Picking rates vary widely from several hundred pounds per hour for light, bulky material to as much as 10 tons for dense rock types. At a labor cost of $1.00 per hour, this corresponds to a cost range from $0.10 to $7.00 per ton.

See also: Refractory; Tin; Wastepaper.

Mechanical sorting. Mechanical sorters utilizing color or radioactivity have recently been introduced. Color difference or radioactivity is detected by a sensing device, which in turn triggers an air blast that blows the sensed particle out of the mainstream of fall. At Eldorado, Canada, uranium ore larger than 3 inches is sorted. A demonstration run in South Africa treated between 25 and 50 tons per hour.

See also: Wastepaper.

WASHING AND SCRUBBING

Washing and scrubbing techniques have been employed to remove minor, fine constituents from the main coarse bulk of a material. If hand sorting is to be employed, removal of these fines may be advantageous in removing surface dirt. Washing and scrubbing can be used if a fine fraction is worthless or if it would create a problem in subsequent separation processes. Clay, for example, is readily removed by washing. Clay left with an ore is troublesome in crushing and grinding, screening, and various separation processes, particularly flotation. A trommel screen equipped with spray nozzles is a good washing device. The tumbling of the material as the screen rotates exerts a scrubbing effect. For heavy-duty work where more scrubbing is required, the log-washer type of equipment is employed.

See also: Pickle Liquor.

GRAVITY SEPARATION

Gravity separation or concentration is based on differences in specific gravity and sizes of materials. Included are jigging, tabling, spiraling, and heavy-media separation. Two particles of the same size but of different specific gravity can be separated, as can two particles of the same specific gravity but of different size. Inasmuch as proper combinations of specific gravity and size will result in a large particle of low specific gravity that reacts to applied forces in the same fashion as a small particle of high specific gravity, sizing prior to separation is desirable for maximum effectiveness. Heavy-media separation is an exception to the foregoing statement in that, regardless of size, specific gravity is the only property that has an effect.

See also: Animal-Product Residues; Wood Wastes; Zinc.

Heavy-media separation. Various solutions or pulps with different specific gravities are available. If a material is immersed in one of these solutions or pulps, it will float or sink, depending on its own specific gravity and the specific gravity of the solution or pulp. Thus, if a mixture of sand of sp gr 2.65 and hematite (Fe_2O_3) of sp gr 5.0 is immersed in a pulp composed of ferro-silicon and water (sp gr 3.0), the sand will float and the hematite will sink, thus effecting a separation.

Although various heavy liquids such as carbon tetrachloride (sp gr 1.67), acetylene tetrabromide (sp gr 2.95), and thallous formate-malonate (sp gr 4.2) among others, have been available, their costs and the problems of recovering them have limited their use to laboratory experimentation. In operating plants, heavy media have found rather wide application. The pulp or heavy medium consists of a mixture of water and fine solids, usually sand, galena, magnetite, or ferrosilicon. Choice of the solid and the ratio of solids to water in the pulp determines the specific gravity of the heavy media. Sand has normally been used for low-specific-gravity media, magnetite and galena for intermediate-specific-gravity media and ferrosilicon for high-specific-gravity media. Maximum specific gravities obtainable have been about 3.2 to 3.4 with ferrosilicon. Use of sand media would normally be restricted to the treatment of coarse, low-specific-gravity materials, the sand being recovered from the separated fractions by washing and screening. When galena is used, the galena is recovered by flotation. Magnetite and ferrosilicon can be recovered by magnetic methods. The upper size limit of material treatable by heavy-media procedures has been about 2 inches, the lower limit about 65 mesh.

Various types of vessels have been used in heavy-media separation, the most popular being cones, classifiers, and drums for particle sizes coarser than about ¼ inch, and cyclones for deslimed feed ¼ inch x 65 mesh.

Capacities of heavy-media units have varied widely, depending on the size of the material, specific gravities, and the closeness of the cut desired. A 4-foot-diameter cone processing 1½ x ⅜-inch iron ore has treated 40 tons per hour.

Treatment cost probably would not exceed $0.50 per ton on coarser materials. Loss of the flotation media and labor, together with the media-recovery system, would account for most of this cost.

Jigging. If a mixture of materials of different specific gravities is placed in a wire-mesh basket and the basket is moved up and down in a container of water, it will be found that after sufficient movement the higher-specific-gravity materials will be concentrated at the bottom of the basket. This is jigging. In commercial practice, a water–solid mixture is passed through a trough or box having a perforated bottom. Water is alternately forced up through the bed and then drawn back down by means of a plunger. This action opens up the bed of material, moving the lower specific-gravity particles farther than the higher. Since the bed compacts on the reverse stroke, the heavier particles move farther than the light particles. As the material passes through the trough or box, this action is repeated a number of times at a rate of several hundred strokes per minute, thus stratifying the material so that it can be separated as it leaves the jigs. The pulsating movement can be obtained by mechanical plunger action or by air, the latter having been the one most used.

Material as coarse as several inches down to about 10 mesh can usually be successfully treated on jigs. Generally speaking, water requirements are high for jigging operations. Skilled labor and close attention has been called for in good jigging operations.

Table separation. Tables are bed-type gravity-separation machines used in the treatment of sand-size materials. The more common tables have been rectangular, the feed being introduced as a slurry at one end of the narrow side of the table. A reciprocating motion is imparted to the table. This motion is normally a slow forward stroke followed by a quick return. Under this action, heavier particles move forward a greater distance than light particles. At the same time wash water is applied across the table at right angles to the direction of movement. The wash water exerts a greater influence on the lighter particles, causing them to move across the table at a greater rate than the heavier ones. The combination of stroke and water [illegible] in a partially diagonal particle movement, with the heavier particles discharging at the end of the table and the lighter ones over the side. The deck may be riffled to aid in the separation. The riffles provide a place for the fine, heavy material to avoid the action of the wash water coming across the table. Space requirements are high, and the shaking action requires substantial foundations. To a considerable extent, tables have been replaced by spirals. For low-specific-gravity materials, tables with porous decks have been available. Air blown through the deck acts as the fluid medium for separation.

The standard Wilfley table is about 17½ feet long and 6 feet wide, requires 1½ to 2 horsepower, and has a capacity of 15 to 150 tons of material per 24 hours.

Spiral separation. The Humphreys Spiral is a gravity concentrating device for the treatment of sand-size material. It consists of a cast-iron trough of curved cross section wound in a spiral with 2-foot outside diameter. The trough contains five or six complete turns, depending on use. The feed in the form of pulp is introduced at the head of the spiral. The heavy material remains in the bottom of the trough and is discharged through ports spaced along the bottom. The lighter material rides up on the side of the trough and is discharged at the end of the spiral. Wash water may be added along the spiral to assist in the separation.

Spirals take up little space, have no moving parts, and are extremely easy to operate. Capacities with ores have ranged from about 1.0 to 0.5 tons per hour.

MAGNETIC SEPARATION

If a mixture contains some parts that are affected by a magnetic field, magnetic separation may be possible. Probably the simplest illustration of magnetic separation is the common use of a magnet head pulley on a belt to remove cans or tramp iron. The nonmagnetic fraction falls vertically, whereas the magnetic material clings to the belt under the influence of the magnet and drops from the belt at a different location.

Magnetic separations can be made dry or wet and with either low or high magnetic intensity. The majority of magnetic separation have used low-intensity separators (5,000 gauss) in removing most ferrous alloys. High-intensity separators (20,000 gauss) may be employed in the treatment of weakly magnetic materials such as hematite and manganese ores.

There are a variety of different types of separators, the belt, induced-roll, and drum being the most common. The magnetic field may be produced by electromagnets or permanent magnets. The latter are becoming more popular because they require no electrical equipment.

Pretreatment may be employed to

TABLE 1

CLASSES OF CHEMICALS USED IN FLOTATION

Classification	Function	Typical chemicals
Frothers	Stabilize froth	Pine oil, cresylic acid, alcohol.
Collectors	Make particles hydrophobic	Xanthates, dithiophosphates, soaps, fuel oil, amines.
Depressors	Make particles hydrophilic	NaCN, various inorganic salts.
pH modifiers	Change pH to intensify effect of other reagents.	Acids and alkalies.

convert a nonmagnetic material to a magnetic one. Hematite, which is nonmagnetic, can be converted to magnetic artificial magnetite by a reduction roast.

See also: Aluminum; Refractory; Slag; Zircaloy.

ELECTROSTATIC SEPARATION

Some materials are conductors of electricity, others are not. If a mixture of conductors and nonconductors is fed onto a grounded, moving roll and charged by means of an electrode, the nonconductors acquire a charge and are pinned to the roll, which they adhere to until brushed off. The conductors, on the other hand, do not acquire a charge and thus discharge from the roll in accordance with their normal trajectory as determined by their mass and the speed of the roll. This method of separation makes use of the so-called pinning effect. A lifting effect can also be obtained, thus altering the discharge paths of the particles.

The same separation effect can be obtained by dropping the material between oppositely charged plates. The path of fall is affected in accordance with the electrical conductivity of the materials.

The application of electrostatic separation has been limited to the range of about 20 to 100 mesh. For maximum effectiveness, the particle bed on the drum or in free fall can be a single layer thick. This naturally limits capacity. Equipment cost has been relatively high because of the auxiliary power facilities required.

FLOTATION

Flotation may be defined as a physiochemical method of concentrating finely divided material. Specifically, the process involves chemical treatment of surfaces in a pulp to create conditions favorable for the attachment of air bubbles to selected particles. The air bubbles carry the particles to the surface and form a stabilized foam that can be scraped off. The unwanted minerals remain in the pulp. In addition to altering surface properties to make certain substances more floatable, it is possible to use various chemicals to reduce floatability.

The surface characteristics of materials can be classified as either hydrophobic or hydrophilic. In flotation, these properties can be altered as desired. The hydrophobic particles attach themselves to the air bubbles and float, while the hydrophilic particles remain in the pulp. Alteration of a surface may result from the reaction or adsorption of flotation-reagent molecules. Flotation reagents that produce hydrophobic surfaces are composed of long-chain molecules that resemble matches, the heads of which represent the end that reacts with the particle. The other end is hydrophobic.

The chemicals that have been used in flotation may be grouped into several classes according to their primary function. Some of the more important are shown in Table 1.

The process is carried out in a flotation machine or cell, which is simply a box that contains an agitator for keeping the solids in suspension. An agitator may provide the air for the air bubbles by aspiration, or air may be added under low pressure directly beneath the agitator. Pulp flows by gravity from one cell to the next. Cells vary from 16 by 16 inches in cross section by 18 inches in depth (2¾ cubic feet) to 56 x 56 x 56 inches (100 cubic feet). The smaller cell would require approximately ½ horsepower; the larger 10 horsepower.

In addition to the individual cell-type construction, other flotation machines are like long, deep troughs with a number of agitators positioned uniformly throughout their lengths.

The number of cells required for any particular operation is a function of the quantity of materials to be processed, the percent solids of the pulp, and the length of flotation time.

The cost of flotation has varied from $0.50 to several dollars per ton, depending on reagent consumption and the complexity of the treatment process. Skilled operators have usually been required, but one operator can ordinarily look after a number of banks of cells.

Flotation has been one of the most efficient and widely applicable separation processes in use. Theoretically, it can be applied to any mixture of particles that are essentially liberated and small enough to be lifted by air or gas bubbles. Particles ranging in size from 20 mesh down to about 5 microns are responsive to flotation separation techniques.

See also: Wastepaper.

SANITARY LANDFILL AND OPEN DUMPING

Probably the most widely used methods for final disposition of solid wastes have been sanitary landfill and open dumping. These have generally cost less than other disposal methods while not creating the acute pollution problem that has often occurred when solids have been discharged directly to waterways or to the atmosphere. However, interest has been growing in methods of disposal other than on the land for several reasons: (1) Land disposal requires large tracts of land. Many communities and industries can no longer obtain the large areas needed. The ever-increasing quantity of waste makes this an urgent problem in some areas; (2) water pollution may result when surface or groundwater leaches the wastes dumped on spoil areas. Even waste materials that are innocuous in themselves often form injurious products upon degradation; (3) air pollution may result from degradation of dumped and improperly covered wastes, either when particles of waste become airborne or when combustible wastes ignite to produce mixtures of particulate and gaseous matter; (4) increased industrial activity results not only in the generation of a greater quantity of wastes, but also in a greater variety of wastes. Thus, the burden imposed on the land, air, and water resources is increasing in magnitude and complexity; (5) certain resources, such as copper, zinc, and lead, are nonrenewable. These materials are squandered when wastes containing them are indiscriminately dumped in spoil areas; and (6) open dump areas are scenic blights and have an adverse effect on land values.

While a properly operated sanitary landfill can greatly limit these adverse effects, especially (2), (3), and (6), development of alternative disposal methods or salvage techniques is a desired goal, because in densely populated areas, space for sanitary landfills is decreasing.

As a consequence of these trends the United States Congress enacted Public Law 89–272, which authorized research and development into improved methods for solid waste disposal.

TYPES OF SOLID WASTES DUMPED OR BURIED

In the questionnaire sent to the State health departments as part of this survey, information was requested concerning the kinds and extent of disposal problems created by solid industrial wastes generated within the State. In the case of 10 States, the reply was that no inventory is made of solid wastes. The remaining 19 States were in a position to give some information as to types of industrial solid wastes disposed of by dumping or burial. No State (except Rhode Island) kept quantitative records, although two States (Georgia and Montana) estimated that the waste from mining was about several thousand tons per day.

Examples of industrial solid wastes disposed of on or in the ground are: papermill residues from waste treatment (Alabama, Georgia, Minnesota, Ohio, Pennsylvania); radioactive wastes (Alaska, South Dakota); heavy machinery (Alaska); mining wastes (Alaska, Arizona, Georgia, Idaho, Minnesota, Montana, Nevada); seafood processing wastes (Alaska); metal refining wastes (Arizona, Minnesota, Nevada, Ohio); quarrying wastes (Georgia, Minnesota); bagasse (Hawaii); potato-processing wastes (Idaho); canning wastes (Idaho); meat-processing and slaughterhouse wastes (Idaho, Minnesota, Nebraska); lumbering wastes (Idaho, Minnesota); rubber wastes (Rhode Island); plastics wastes (Rhode Island); textile wastes (Rhode Island); chemical wastes (Minnesota, Rhode Island); oils (Rhode Island); buffing wastes and leather scraps from tanneries (New Hampshire); sawdust and shavings from sawmills and woodworking plants (Minnesota, New Hampshire, North Carolina); scrap from shoe factories (New Hampshire); brickyard wastes (New Hampshire); wastes from the investment casting process (New Hampshire); coal-washing fines (Ohio); fly ash from power plants and ashes from various other industries (Minnesota, Ohio); precipitates from treatment of metal-finishing wastes (Minnesota, Ohio, Pennsylvania); coal refuse (Pennsylvania); and lime sludge from beet-sugar processing (Minnesota).

A report from Rhode Island titled, *Refuse Disposal in Rhode Island*, probably the best source of information on disposal of industrial solid wastes, stated that: "Officially or reliably, there is little known about the disposal of industrial wastes. Certain general information is available that may give some ideas on the quantities, types, and expected problems involved in this aspect of solid wastes disposal." Data on the quantities of solid wastes produced by industries in Rhode Island were presented, but since the units were not clear, the data are omitted from the present report. Knowing the number of manufacturing employees in each of these industries, and assuming that costs of disposal average $8.00 a ton, it was calculated "that Rhode Island industry may expend $750,000 to $1,000,000 per year for solid waste disposal." [274]

In a report of a study made in the San Francisco Bay area, it is recommended that there be detailed reporting of solid waste production by industries.[20]

In addition to describing kinds of wastes, some States also responded with information on the methods of solids disposal. It was reported that in Georgia sludges and muds from mining, quarrying, metal finishing, and papermaking are normally impounded in low areas for sedimentation with the sedimentation basins being abandoned when they are filled. In Nebraska, slaughterhouse wastes are spread in open fields where they are later disked in. Meat-processing plants in Nebraska dump grease slurries in open pits.

INCINERATION

The incineration of municipal refuse has been treated in detail in *Municipal Refuse Disposal* but a brief review of some of that information is given here so that an integrated discussion can be presented. For details, the original work should be consulted.[34] Part of the experience municipalities have had with waste incineration can be applied to incineration of some industrial wastes.

GENERAL CHARACTERISTICS OF THE INCINERATION PROCESS

The complexity of an incineration plant increases with its capacity and the existing air-pollution standards. Some general characteristics of the incineration process are: (1) when well operated it disposes of the health problems associated with refuse accumulation and reduces waste volume at least 60 percent (more frequently 80 to 85 percent) in a central plant with minimum nuisance; (2) it is adaptable over a wide range of equipment capacities, such as from small domestic incinerators to large centralized municipal incinerators with capacity of 1,000 tons per day or more; (3) it can handle the mixture of garbage and rubbish which results from the currently favored single-collection method; and (4) the passive character of the clinker produced in properly operated furnaces considerably aids its ultimate disposal.

Incineration costs reported by Rogus in 1955 showed a decline of from $4.78 per ton in older New York City plants to $2.50 per ton in a new plant, and $2.39 per ton cost for a new Rochester, New York, plant.[381]

Gilbertson and Black quoted a charge to homeowners in the Washington suburban sanitary district of $36 per year for refuse service, and state that at least 85 percent of the total cost of providing refuse service is spent on collection.[154] Assuming an annual load of 2.5 tons of refuse per household and an incineration cost of about $3.00 per ton, the incineration process might cost an average of $7.50 per household. Making some allowance for present cost of landfill (assumed at $1.00 per ton), complete conversion to incineration might raise the Gilbertson and Black figure by approximately 15 percent.

The furnace, as either a single or

a multiple unit, is essential to all incineration plants. A secondary chamber provides space for the complete combustion of unburned furnace gas and elimination of odors from stack gas and for the destruction of the organic content of any solids carried by it. This secondary chamber may be integral with the furnace.

A gas cooler usually precedes the solids separator, since available separators have not operated at temperatures usual for exit gases from the secondary chamber.

It was reported that Dorr-Oliver supplied a system using high-speed centrifugal dewatering teamed with thermal oxidation in a fluidized (sand) bed reactor to incinerate sludge.[326]

Fly-ash emission is determined by plant design and operating conditions. Schwarz described measures to be taken by incineration plants to control air pollution. Fly ash increases with burning rate, air rate, or agitation.[400] Some idea of particle size and analysis was given in *Municipal Refuse Disposal*.[54] The fallout that occurred in an area around an incineration plant in Paris, France, was reported by Chovin.[76]

Dry collection of fly ash includes the use of refractor baffles, low-velocity subsidence chambers, and multicyclone centrifugal separators. But such methods have been hardly adequate to meet the fly-ash limitations recommended by the American Society of Mechanical Engineers (see comments of Ellsworth and Engdahl).[125] Electrostatic dust precipitators, as have been used in Europe, have been discussed by Bump.[63]

Wet collection employs either water sprays or impingement on a wet surface. Results by various methods have been reported by Fife and Boyer [135] and by Vickerson.[467]

The nature of incinerator slags has been discussed by Herbert [184] and Regis.[369]

KINDS OF FURNACES

Michaels listed three types of refuse furnaces [297]: (1) The single-chamber, cylindrical, batch-feed type. This is a refractory-lined furnace charged through a door in the upper part of the furnace. Refuse is dropped into the furnace periodically and stoked to the periphery manually or mechanically by a rotating cone with extended rabble arms. The dumping grates are located around the periphery and are operated whenever the accumulation of ash warrants removal; (2) the single- or multiple-cell, rectangular, batch-feed type. This may be a refractory-lined or water-cooled furnace with a charging door in the middle or near the back of the ceiling of each cell. It is equipped with either fixed or moving grates set level or inclined; and (3) the continuous-feed type. The major mechanical difference between this and the batch-feed types is obvious from the names: refuse is fed into one in batches; into the other continuously. Ashes are also removed continuously, and an air seal is maintained with the furnace continuously. The inclined, rotating-kiln type is essentially the same as the continuous-feed type, except that it has a refractory-lined, slowly revolving cylindrical kiln that is used in the final burning stage.

In the continuous-feed types of furnaces, the grates are the traveling type, inclined, flat, or a combination; the furnaces require a minimum of manual stoking.

Usually, all three types of furnaces are lined with refractories and insulating brick.

Various designs are shown in the literature. These include cross-section drawings [84] of the furnaces of the Calumet incineration plant in Chicago, the Northwest plant in Philadelphia, a modern continuous-feed-type incineration plant, the Volund rotating-kiln incinerator, a continuous-feed grate, the Saint-Ouen (France) plant,[402] and the Fort Lauderdale incinerator.[84]

INDUSTRIAL INCINERATION

The use of incinerators for disposal of solid industrial wastes appeared to be very limited. Fourteen States responding to the survey questionnaire reported that the kind and amount of industrial solid wastes incinerated were unknown.* California reported that there was little incineration because of air-pollution regulations and economics. The only industry in that State which carried on extensive burning was agriculture, which was exempt from air-pollution laws. Idaho reported that although no industries incinerated wastes, many of them did burn wastes prior to dumping.

Solid industrial wastes reported as being incinerated were sawmill and lumber-industry wastes, corncobs, bagasses, packing material, and textile rejects. "Tepee" type burners were often used to burn sawdust and corncobs in four States.† Bagasse was incinerated for fuel in Hawaiian sugar mills. A kraft pulp mill in one state

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***Arizona, Arkansas, Colorado, Kansas, Kentucky, Maine, Missouri, Montana, New York, North Carolina, Pennsylvania, Texas, Washington, Wyoming.**

†Nebraska, New Hampshire, South Dakota, Utah.

dried and burned its sludge in bark-burning boilers. Georgia's mills were also considering this method of disposal. In that State, most industries maintained burning areas where dry, combustible solids such as packing material and textile rejects were incinerated, and some industries maintained regular incinerators for this purpose. A chemical industry had adopted incineration on an experimental basis in Minnesota.

Only Tennessee reported that many industries in the State incinerated solid wastes. Incineration of wood wastes was reported to be fairly common in the lumber industry in Minnesota.

The general overall approach to industrial incineration is presented in two papers,[430, 489] and design criteria are reviewed in several.[94, 280, 306, 497, 519] Thermodynamic calculations require specific information on the amounts of combustibles, their density, moisture, and calorific values, availability of carbon, hydrogen, oxygen, etc. Their abrasive and corrosive action on grates, refractories, and other materials must be considered. Practically no information of this sort was available for some of the newer special wastes, for example, various synthetics and chemicals.[280] The heating values of various fuel materials together with the heating values of various wastes have been reported.[187, 501]

Incineration provides an effective method to remove combustible materials from scrap metals. It has been widely used to burn the insulation from copper wire and cable. The practice of burning piles of insulated wire in open fields formerly was widespread, but has become rather limited. According to Lipsett the adoption of plastic for insulation and stringent pollution regulations have introduced serious difficulties in removing insulation from wire.[264] He stated in 1963 that fortunes have been spent on facilities to remove the new insulating compounds from the wire, but that most of the installations were not entirely satisfactory in the abatement of the smoke nuisance.

See also: Chemical Wastes; Paint; Petroleum Residues; Pulp and Paper.

CAPITAL COSTS

Michaels noted that municipalities tend to have a different view of capital costs than private enterprises.[297] A municipality attempts to keep capital charges low to minimize the financing required—usually a bond issue—particularly since the administration that builds the plant may not have to operate it. This explanation accounts in part for the wide range in capital costs of various plants as from $1,000 to $5,000 per ton of capacity. This approach tends to reduce the premium on good operability and design.

Construction costs were described in *Municipal Refuse Disposals:* "Most incinerator plants cost from $3,000 to $4,000 per ton of rated 24-hour capacity to build and equip. Buildings account for from 40 to 76 per cent of total costs (an average of 58 per cent furnaces and appurtenances account for from 18 to 44 [sic] per cent of the total (the average 35 per cent); and the chimney accounts for from 4.5 to 11 per cent (the average 7 per cent).

"Construction costs adjusted to 1957 levels reported for 21 incinerators built since 1949 (16 since 1954) had a median of $3,650 per ton of capacity. This compares to a median cost for 1946 of $2,000 a ton, or an increase of approximately 82 per cent in 11 years. General construction costs for the same period increased approximately 100 per cent."[94]

Construction costs for New York incinerators have been separated by the following functions: architectural and structural; mechanical; electrical; heating; ventilating; plumbing; and miscellaneous (Table 2).

Greeley estimated that about 40 per cent of the cost of an incinerator was for furnaces and appurtenances, and above 60 percent for building, chimney, approaches, and storage bin[163] (Table 2). Greeley also estimated the relative costs for parts of the installation (Table 3).

Michaels tabulated incinerator construction costs for 25 incinerators.[297] Data were given on the location; capacity; year completed; material burned; type of grate; number of furnaces; capacity of each furnace; combustion chamber volume; type of dust-collection system; number, height, and diameter of stacks; type of wall construction in furnace, chamber, and flue; waste-heat utilization; plant operation; and cost of plant.

Coal-fired powerplant experience provides a guide to possible first costs of incinerator collection. The capital investment in equipment installed at the South Charleston, West Virginia, powerplant of the Union Carbide Corporation for the collection of fly ash, has been given by Magnus.[272] Costs were given for both electrostatic and

TABLE 2

PRINCIPAL COMPONENTS OF A MUNICIPAL INCINERATOR AND COSTS[163]

Item	Illustrative unit cost/ton of rated capacity (dollars)
Scales, scale house, entrances and exits, maneuvering yard, dumping rail, and enclosing wall	$100
Storage bin	200
Cranes	225
Outsides flues and fly-ash-removal facilities	400
Chimneys	300
Miscellaneous items, such as drains, piling, and wood-hogs	75
Furnaces	1,200
Inside flues	85
Building and enclosures	1,415
Total	4,000

TABLE 3

FIRST COST DISTRIBUTION FOR PARTS OF AN INCINERATOR INSTALLATION[163]

Part	Approximate percent of total cost
Scales, yard, storage bin, and outside appurtenances	11.0
Building and cranes	37.0
Furnaces, combustion chambers, flues, and appurtenances	35.0
Relatively simple fly-ash-removal facilities	7.0
Chimney	10.0
Total	100.0

baffle-type collectors as well as the 1963 costs for replacing this equipment, the steam-generating rates of the equipment, and the costs of the equipment on a cost-per-pound-of-steam basis (Table 4). Magnus states that the cost of mechanical collectors and electrostatic precipitators is roughly $0.15 and $0.55 per pound of powerhouse steam-generating capacity, respectively.

OPERATING COSTS

Michaels noted difficulties in comparing operating costs between various plants. "Determining typical operating costs is rather difficult because some municipalities include the cost of removing residue; others exclude maintenance costs, etc. However, a plant containing an average amount of mechanization, operating on a 24 hr a day basis, and having a minimum capacity of 300 tons/day, if efficiently run, should cost between ½ and 1 man-hour/ton to operate. Obviously, the type of material handled, i.e., mixed refuse, garbage, rubbish, etc., the degree of mechanization, the air pollution and other health standards to be met, and the housekeeping standards all have a bearing upon the ultimate operating costs. The customer should be aware of these factors and should be able to advise the consulting engineer of the standards he requires."[297]

Rogus reported overall operating costs. "In 1953, landfill cost was $2.26/ton while the average incineration cost of 12 plants was $4.78. However, the new Gansevoort Incinerator has averaged only $2.50/ton. A new plant at Rochester, New York, is reported to have a basic operating cost of only $2.39/ton including the cost of operating a stack-gas washer. The initial cost of the plant was $1,373,726. Hence, it appears that incinerator operating costs are becoming competitive with landfill costs and the principal remaining problem is to assure their clean operation."[381]

A higher plant cost can provide a lower operating cost[34] (Table 5).

Providing for 24-hour furnace operation has been shown to be desirable by comparison of the daily average operational costs, in dollars per ton of furnace, for 1-, 2-, and 3-shift operations.[34] But collection on an 8-hour-per-day basis necessitates buffer storage capacity the size of which should provide for variations in the foreseeable future in amount and character of the incoming refuse.

TABLE 4

CAPITAL INVESTMENT IN EQUIPMENT FOR FIY-ASH COLLECTION AT THE SOUTH CHARLESTON, WEST VIRGINIA, POWERPLANT[271]

	Collection equipment	Total installed cost ($)	Replacement cost ($) [a]	Steam generating rate (lb/hr)	Capital cost per pound of steam per hour ($)
(1)	Precipitators (Boilers 9 through 13) (1947)	270, 711	528, 000	410, 000	1. 29
(2)	Mechanical separators (Boilers 9 through 13) (1937)	59, 346	174, 000	------	----
(3)	Precipitators (Boilers 14 and 15) (1942)	79, 084	205, 000	300, 000	0. 68
(4)	Precipitator (Boiler 16) (1945)	35, 236	81, 800	150, 000	0. 55
(5)	Precipitators (Boilers 17 and 18) (1944)	74, 974	178, 000	300, 000	0. 59
(6)	Precipitator and mechanical separator (Boiler 25) (1954)	104, 804	135, 500	289, 000	0. 47
(7)	Mechanical separators (Boilers 30 and 31) (1961–64)	43, 646	43, 646	300, 000	0. 14
	Total	667, 853	1, 345, 946		

[a] 1963 equipment and labor cost index = 1.0.

TABLE 5

COMPARATIVE COSTS OF TWO TYPES OF INCINERATORS IN NEW YORK CITY (195[illegible] COSTS)[34]

Cost item	Cost	
	Mechanized continuous type (average for 3)	Manually stoked batch type (average for 4)
Total construction costs per ton per day of capacity (including engineering but exclusive of land)	$5, 500. 00 [a]	$3, 750. 00
Total operating costs per ton of refuse destroyed	5. 55	7. 50
Operating less residue disposal	2. 40	4. 20
Maintenance and repair	1. 05	1. 05
Administration and supervision	0. 50	0. 65
Pension	0. 60	0. 90
Fuel and utilities	0. 05	0. 05
Amortization	0. 95	0. 95

[a] Two plants have since been constructed elsewhere for $3,600 per ton per day.

Recommended storage capacity ranges were between 12 and 36 hours of plant capacity.[84] A 1000-TPD New York City plant design provided 1 ton of liquid-level pit capacity per ton per day of plant capacity. One ton of liquid-level pit capacity was considered equivalent to 6 cubic yards of truck-compacted refuse.

Storage and handling facilities should provide for handling objects at least 80 inches square according to Wiehrmann.[482]

It was pointed out that operating costs also varied widely, depending on the type of refuse burned and the thoroughness of the burning, the degree of sanitation controls exercised, the type of incinerator plant and the extent of its mechanization, the wage scale and amount of fringe benefits, and the productivity of labor and efficiency of management.[84] Operating costs for six cities were compared (Table 6).

Maintenance and repairs were commented on. "The modern incineration plant is dirty, dusty, odor producing, and requires more than normal routine care to even approach a power plant in spit-and-polish appearance and trouble-free operation.

"An annual budget for maintenance and repairs approximating 5 percent of the total capital costs of the plant usually is adequate, particularly if the plant is well designed and constructed; if it was properly tested, adjusted, and broken in; and if it is always kept in good condition. Maintenance and repairs can be expected to cost between 10 percent and 15 percent of the total cost of operation, depending on the size and type of plant. Approximately half the cost will be for labor and the other half for materials.

"Routine maintenance is preventive. Weekly inspections, cleaning, and greasing, removal of clinkers and slag, minor repairs to easily accessible parts of the plant and machinery, and less frequent inspections and repairs to hard-to-get-at parts of the plant will help prevent major damage and emergencies.

"In addition to routine maintenance and repairs, major repairs are needed occasionally; reconstruction and modernization of furnaces, cranes, and other parts of the plant are needed less frequently; and a complete overhaul and modernization of the plant is necessary perhaps every 25 years or so." [84]

Refuse storage to afford 24-hour operation minimizes the installation size and its operating cost. Grab-bucket crane material handling equipment is more suitable for bulky objects than a conveyor system according to Wiehrmann.[482]

Some indication of operating costs of electrostatic precipitators is provided from power plants. The total cost of collecting fly ash at the South Charleston Union Carbide coal-fired plant with eight electrostatic precipitators was reported as $31,500 per year with a breakdown of this cost and operating costs on a unit basis (Table 7). Seven of the precipitators were equipped with 25-kva double-halfwave mechanical rectification units, while the precipitator of Boiler 25 was supplied with a vacuum-tube rectifier (a 75-kv 25-kva full-wave Kenotron unit).

The costs of constructing and operating air pollution control equipment as required to meet various municipal incinerator stack emission limits were reviewed by Fife and Boyer.[135] Rogus has reported foreign costs for Western Europe.[377] The total costs of on-site domestic incineration have been estimated by Engdahl and Hein to be higher than for municipal disposal.[128]

Certain economy in plant cost results from the use of a dust separator, since higher gas velocities then become permissible in the preceding

TABLE 6

OPERATING COSTS FOR MUNICIPAL INCINERATORS IN SIX U.S. CITIES [a]

City	Cost per ton of refuse processed
Philadelphia	$4. 24
Washington, D.C.[b]	2. 28
Detroit	4. 30
Milwaukee	6. 49
New York City[c]	5. 55
Los Angeles	3. 13

[a] Costs are for one plant in each city in 1959, except for New York, where the cost is the 1958 average for three plants.

[b] Does not include amortization costs.

[c] Cost computed on basis of tons burned (amount charged minus residue).

TABLE 7

ANNUAL COSTS OF OPERATING ELECTROSTATIC PRECIPITATORS AT THE SOUTH CHARLESTON, WEST VIRGINIA, POWER PLANT [273]

Cost item	Total annual cost of all units	Annual cost of mechanical rectification (unit basis)	Annual cost of vacuum tube (unit basis)
Operating labor	$12,460	$1,558	$1,558
Electric power	7,875	1,680	895
Water	1,002	127	127
Repair labor	9,027	[a] 723 [b] 425	[a] 134 [b] 855
Repair material	1,136	116	210
Total	31,500	4,629	3,779

Factors:

Number of units: 7 with mechanical rectification, 1 with vacuum-tube rectification.
Labor, $4.45 per hr (hourly rate plus fringe benefits).
Power, $6.00 per mkwh.
Water, $160 per mmg.

[a] Daily maintenance.

[b] Semiannual overhaul.

parts of the plant which operate at high temperatures and therefore are of more costly construction. Usually an efficient collection device is needed to reduce the amount of suspended particulate solids in the stack gas to the desired air pollution limit.

Several references concerning the use of afterburners to combat the smoke from incinerators appear in the literature.[197 538] Houston stated that burning was the best method for removing insulation from copper wire, but that this required incineration with proper smoke controls. He added that probably the cheapest way to control smoke would be by burning the insulation with an afterburner, a secondary combustion chamber maintained at 1,800° to 2,200° F. by burning oil or gas.

Houston also claimed that if afterburners were well designed and were operated properly, the matter released to the atmosphere would be reduced to a light haze. He estimated that the bare, direct cost of the smallest practical incinerator unit and the cheapest method of smoke control would be between $11,000 and $14,500. That estimate was published in May 1957.[197]

Salvage and sorting have not been considered rewarding beyond the improvement they have afforded in handling and in the uniformity of feed and the combustibility of the refuse. Similar benefits result from grinding, but some sorting is usually required to protect the grinders.

While it may be advantageous to remove metal, large objects, and noncombustibles from refuse in preparation for charging it into the incinerator, experience in the United States has indicated that salvage operations and reduction processes have generally not been profitable.

The appearance of new products such as plastic packaging materials in refuse, and therefore in the furnace feed, can produce certain gaseous decomposition products necessitating stack-gas treatment. The requirements for such treatment would be difficult to predict.

Designs and performance of equipment for the control of air pollution from municipal incinerators have been discussed in detail by Jens and Rehm.[235]

WASTE-HEAT RECOVERY

A few combustible industrial wastes generated in manufacturing processes have normally been used as fuel by the organizations that generate them. Useful heat is required for generation of process steam or electric power.[127] Usually, this has been done in conventionally designed boilers and furnaces, with perhaps specialized equipment installed only for conveying and feeding the combustible material into the combustion chamber.[27 103 296 410] Similarly, the recovery of useful heat from the incineration of mixed solid municipal wastes and sewage sludge has been practiced extensively in Europe,[118, 309, 377] but not in the United States because of the generally unfavorable fuel economics for waste-heat recovery.[427] If in addition to whatever fuel saving is possible, however, some value were placed on ease of handling of a refuse disposal problem and on environmental quality (air purity and land beautification), heat recovery from the combustion of municipal waste could be made more attractive. The outcome of each analysis will depend on specific local conditions and standards of environmental quality. In many locations waste-heat recovery may not seem justified for many years.[430]

Heat available. The long-term trend has been for the cellulose content of municipal solid waste to increase with decreasing moisture; hence, the heat value from combustion of the waste has been rising. In the United States, it was estimated to be about 5,000 Btu per pound, with the likelihood that by 1980 it would have reached 5,500 Btu per pound. This trend will probably have some effect on increasing the feasibility of waste-heat recovery.[407]

Methods of heat recovery. The simplest method of waste-heat recovery from municipal incineration has been the incorporation of a waste-heat boiler immediately following the incinerator for the regeneration of hot water or steam. One disadvantage of such a system has been that the refractory-lined furnace would be unable to withstand the temperature generated by stoichiometric combustion of the waste; hence, the chamber must be cooled by dilution of the combustion gases with excess air. The logical alternative to this less efficient system is the construction of an integral boiler, the furnace lining being formed by steel tubes to provide a water-cooled incinerator chamber. This has been demonstrated to be highly successful in many installations in Europe. One difficulty has been with boiler-tube corrosion due to sulfates or chlorides on the fire side of the tubes. This attack has appeared to be a function of steam temperature; that is, if steam temperatures can be held below 1,000°F., little or no tube attack should occur.

An alternative method of heat recovery is to have an air-heater type of heat exchanger following the incinerator chamber. Again, this might be very inefficient because excess air would be needed to cool the flame to protect the refractory walls of the incinerator, and the temperatures of the gas-to-air heat exchanger metal would have to be held to moderate levels to give reasonable heat-exchanger life. All of these methods must be designed to cope with extremely dusty gas probably involving some adhesion of the dust to the tubes.

Applications for recovered heat. If the waste heat is recovered as steam, it can be utilized for turbine drives for the auxiliary equipment on the plant, such as blowers and pumps. Alternatively, the turbine can drive an electric generator for the generation of electric power for internal use in the plant or for sale. If the plant is located adjacent to a populated area, the steam can be used for district heating or for industrial processing. A plant has been installed for combination of seawater distillation with incineration.[462] Instead of steam, the heat can also be recovered in the form of hot water, which can be used for heating the premises or for sale in the neighboring area.[361] This has been done extensively in Denmark.

Performance of heat-recovery systems. The amount of steam generated per pound of refuse burned depends on many factors.[102, 461] The most efficient generation has been in water-tube-wall boilers operating with low excess air without interruption for 24 hours a day. In general, to achieve satisfactory heat generation, it has been necessary to provide auxiliary fuel to maintain constant generation because of the varying moisture content of the refuse and the varying supply of refuse.

In general, the reliability of a water-walled waste-heat boiler will be highest of all, unless tube temperatures are carried so high that corrosion is a problem.

Economic incentive for heat recovery. The value of the heat recovered will be determined by the cost of using competitive fossil fuels and upon the load factor that needs to be maintained for the particular use intended. A major economic advantage to the recovery of heat, particularly where environmental quality is considered important, has been the volume effect of the extraction of heat from exhaust gases in the furnace and the use of less excess air because of the completely water-cooled furnace. Both of these factors have greatly reduced the volume of dusty gases to be cleaned, and hence have reduced first costs, operating costs, and maintenance costs of suitable dust-collecting equipment.

CHEMICAL PROCESSING

Chemical processing of solid wastes for recovery of usable materials and energy is inherently one of the most appealing approaches to the disposal problem. In practice, however, such processing has often proved costly. In addition to the many articles cited, this survey of published information on chemical processing covered *Chemical Abstracts*, *Engineering Index*, and *Industrial Arts Index* for the period 1950 to 1966. Public Health Service Publication No. 91, Bibliography Series No. 4, Supplement E, entitled *Refuse Collection and Disposal 1960–1961*, was reviewed also.

Twenty-nine processes of interest were identified. The list includes some processes that are physical rather than chemical to insure that this section of the report covers all "nonmechanical" processes: acidification; alcoholysis; calcination; carbonization; chlorination; combination and addition; combustion (incineration); condensation; dehydration, dewatering, and drying; dilution; displacement; dissolution; distillation; electrolysis and electrodialysis; evaporation; extraction; hydrogenation; hydrolysis; ion exchange; melting; neutralization; nitrogenation; nitration, and ammoniation; oxidation (chemical); polymerization; precipitation, crystallization, and gelling; pyrolysis; reduction; sintering; vaporization and gasification.

Two main groups of chemical processes can be distinguished, the determination depending upon whether entirely new products are obtained in the course of treatment or whether only a recovery of existing raw materials takes place. The classification differentiates between the manufacture of new products and reclamation processes. The latter are cyclic processes. Waste products in the true sense do not occur. The term is commonly used, and is used in this study even though at the present time many materials are or could be recycled instead of simply being processed as wastes.

Ideally, the techniques used for disposal of solid wastes should: (1) Produce a revenue or at least cost the producer little or nothing; (2) consume most of the material; (3) be of a nonseasonal nature; (4) produce an end product that contributes some beneficial results to the economy of the country; (5) not result in pollution of the environment.

Selection of techniques for inclusion in this study, however, was not ordinarily limited by these criteria. Processes that consume very small amounts of waste—10 percent or less—were excluded, on the other hand, as offering no appreciable reduction of the solid-wastes problem.

Although this has been essentially a study of the waste problem in the United States, techniques for chemical reduction of solid wastes described in the foreign literature are covered even though it is recognized that one of the basic problems of effective disposal is economics and that economics are different for every area of the world. A number of articles and patents are considered, although evidence of industrial practice was lacking, because air, land, and water pollution control and conservation of resources are becoming more urgent all the time. In the future these may alter the economics of some solid waste disposal processes. In some cases, the processes decribed in the literature may not have survived because of economic or other conditions. Nevertheless, knowledge of their temporary demonstration or use may be helpful in similar circumstances.

The literature reviewed showed that although chemical processing of some solid wastes for salvage and recovery is technically feasible, there has been limited interest in these processes not only because of problems of economics and marketing, but also because of impurities and nonuniformity of quantity and composition of the waste material.

It was apparent from the literature and from correspondence with State health departments that there have not been many commercial applications of chemical processes for treating solid industrial wastes. A few industries have incinerated solids. Many more have burned wastes in open dumps. The most common method of disposal has been to accumulate solid wastes in spoil areas. This choice has been dictated by economics. Land disposal has nearly always been selected as the cheapest method. Most chemical processes require a substantial capital investment, and the cost of operation has also been significant. As long as justification for chemical processing of waste is based solely on the ability to sell the products above fixed and operating costs, there is little chance that these processes will be adopted. If poor public relations are engendered by pollution or unsightly conditions, chemical recovery processes may nevertheless become necessary.

The chemical processes described in the literature are reviewed here briefly in the order of the frequency of their appearance in the literature. The literature on acidification, chlorination, condensation, dehydration, dilution, displacement, dissolution, hydrogenation, neutralization, nitrogenation, polymerization, reduction, and vaporization of solid industrial wastes was found to be very scanty. No reference to commercial applications of any of these processes was found. More detailed discussions will be found in the "Major Waste Categories" section of this report.

HYDROLYSIS

Hydrolysis provides a means for utilizing agricultural residues and wood wastes. Its potential application is worldwide. Glucose is obtained by hydrolysis of the cellulose portion of plants. Hydrolysis of the hemicelluloses in plants yields pentoses, which upon dehydration form furfural, an important raw material for plastics. The lignin remaining after recovery of these hydrolysis products is a potentially valuable chemical raw material. Lignin can also be hydrolyzed. When plant residues are used for manufacture of paper, board, and rayon, it is the lignin that is hydrolyzed to alcohols and acids in order to recover cellulose fibers from the waste. At least one plant in the United States has hydrolyzed lumber and pulp-mill leftovers to obtain glucose. A number of sulfite mills have produced alcohol with yeast from the glucose formed in pulping process. This is justifiable as a means of reducing stream pollution. A review of hydrolysis equipment has been made by Taubin.[410]

See also: Agricultural Wastes; Animal-Product Residues; Bagasse; Brewing, Distilling Fermenting Wastes; Food-Processing Wastes; Fruit Wastes; Germanium; Leather Fabricating and Tannery Wastes; Plastic; Pulp and Paper Wastes; Textiles; Vegetable Wastes; Wood Wastes.

COMBUSTION (INCINERATION)

Combustion or incineration has appeared to offer the most hope for implementation in the near future. It has the advantage of providing the ultimate in volume reduction, and frequently it is the most practical way to treat toxic substances. Although chemical recovery is possible in some cases (e.g., recovery of chemicals from black liquor for sulfate pulping), heat is generally the only salvageable by-product. Air pollution control measures may limit this practice in some areas or call for advanced design and process control.

See also: Animal-Product Residues; Asbestos; Ash, Cinders, Flue Dust, Fly Ash; Bagasse; Brewing, Distilling, Fermenting Wastes; Brick Plant Wastes; Chemical Wastes; Coal Refuse; Electroplating Residues; Gypsum; Molasses; Organic Wastes; Paint; Pulp and Paper; Petroleum Residues; Photographic Paper; Plastic; Rubber; Sulfur; Wood Wastes; Yttrium.

EXTRACTION

Extraction of constituents from waste solids by means of solvents has been an important means of obtaining salable chemicals and metals. However, the high cost of most solvents has limited the commercial value of many of these recovery processes.

See also: Agricultural Wastes; Alumium; Animal-Product Residues; Brewing, Distilling, Fermenting Wastes; Coffee; Fish; Fruit Wastes; Glass; Manganese; Nuts; Pickle Liquor; Plastic; Poppy; Pulp and Paper; Sisal; Titanium; Vanadium; Vegetable Wastes; Zinc.

PYROLYSIS*

Pyrolysis of carbonaceous waste materials leads to recovery of a number of by-products, the most important of which is charcoal. Pyrolysis has been practiced on a commercial scale in the United States. The atomized-suspension technique is useful for pyrolyzing sludges.

See also: Animal-Product Residues; Fruit Wastes; Leather Fabricating and Tannery Wastes; Petroleum Residues; Plastic; Pulp and Paper; Rubber; Vegetable Wastes; Wood Wastes.

CARBONIZATION*

Carbonization of carbonaceous wastes has been practiced to obtain activated carbon. It has been carried out on a commercial scale.

See also: Brewing, Distilling, Fermenting Wastes; Food-Processing Wastes; Petroleum Residues; Rice; Textiles; Wood Wastes.

OXIDATION (CHEMICAL)†

Chemical oxidation of organic waste materials yields a variety of products, but there has not been much commercial application of this process. Some use has been made of bagasse and sawdust as reducing materials in metallurgical operations.

See also: Bagasse; Carbides; Chemical Wastes; Food-Processing Wastes; Inorganic Wastes; Pulp and Paper; Rubber; Wood Wastes.

SINTERING

Sintering has been practiced for recovery of metals and for converting wastes to a form usable in building materials, particularly for utilization of slag and fly ash.

See also: Aluminum; Ash, Cinders, Flue Dust, Fly Ash; Bauxite Residue; Coal Refuse; Cobalt; Inorganic Residues.

PRECIPITATION, GELLING, AND CRYSTALLIZATION

Precipitation, gelling, and crystallization have limited application for processing solids industrial wastes. Some metals (e.g., silver) have been recovered by precipitation.

See also: Animal-Product Residues; Copper; Fish; Fruit Wastes; Gypsum; Leather Fabricating and Tannery Wastes; Pickle Liquor; Pulp and Paper; Titanium.

CALCINATION

Calcination has had fairly widespread application for the recovery of calcium compounds, such as lime and gypsum, from sludges. A continuous calciner which reduces aqueous waste concentrates to anhydrous melts has been described by Hittman.[158]

See also: Acetylene Wastes; Asbestos; Calcium; Coal; Pickle Liquor; Pulp and Paper; Slag; Titanium.

MELTING

Melting residues to recover metals such as copper, iron, zinc, and lead has been practiced. Silicon-containing wastes have also been melted for by-product recovery.

See also: Animal-Product Residues; Ash, Cinders, Flue Dust, Fly Ash; Brick Plant Waste; Copper; Glass; Lead; Pulp and Paper; Plastic; Titanium.

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*The terms pyrolysis and carbonization are not entirely interchangeable, although carbonization may be considered as a special case of pyrolysis in which volatiles are cooled sufficiently rapidly to prevent further decomposition (cracking).

†This term refers to oxidation by chemically combined oxygen, such as contained in HNO_3, Fe_2O_3, etc. It thus differs from combustion, which involves oxidation with free oxygen.

ELECTROLYSIS AND ELECTRODIALYSIS

Electrolysis and electrodialysis can be used to recover iron and acid from spent pickling solutions and to recover chemicals from spent sulfite pulping liquor. A pilot plant has been in operation for treating sulfite waste in this manner.

See also: Beryllium; Manganese; Pickle Liquor; Pulp and Paper; Titanium.

COMBINATION AND ADDITION

Combination and addition reactions are steps in the production of dimethyl sulfide and sulfoxide from the lignin in kraft black liquor. This has been used on a commercial basis.

See also: Calcium; Pulp and Paper.

EVAPORATION

Evaporation has been used to recover salable solids from waste liquors. Steep water, whey, and beet pulp have been evaporated and used for feed. Copperas has been recovered from pickle liquor by evaporation. Lignosulfonates have been produced by evaporation of sulfite liquors.

See also: Brewing, Distilling, Fermenting Wastes; Pickle Liquor; Pulp and Paper; Starch.

ION EXCHANGE

Ion exchange can be used for the recovery of chemicals from the soluble-base (sodium, magnesium, ammonium) pulping liquors.

See also: Ash, Cinders, Flue Dust, Fly Ash; Pulp and Paper.

MISCELLANEOUS PROCESSES

Acidification

See: Ash, Cinders, Flue Dust, Fly Ash; Wood Wastes.

Alcoholysis

See: Plastic.

Chlorination

See: Carbonaceous Shales; Fruit Wastes.

Condensation

See: Plastic; Wood Wastes.

Dehydration, dewatering, and drying

See: Coal; Food-Processing Wastes; Pulp and Paper; Wood Wastes.

Dilution

See: Chemical Wastes.

Displacement

See: Calcium; Pickle Liquor.

Dissolution

See: Leather Fabricating and Tannery Wastes; Plastic; Pulp and Paper.

Distillation

See: Chemical Wastes; Food-Processing Wastes; Fruit Wastes, Petroleum Residues; Plastic; Pulp and Paper.

Hydrogenation

See: Pulp and Paper.

Neutralization

See: Chemical Wastes; Pickle Liquor.

Nitrogenation, nitration, and ammoniation

See: Bagasse; Carbonaceous Shales; Plastic.

Polymerization

See: Bagasse; Paint; Plastic.

Reduction

See: Copper; Lead.

Vaporization and Gasification

See: Ash, Cinders, Flue Dust, Fly Ash.

RECOVERY AND UTILIZATION

The disposal of solid waste materials frequently involves their direct ultimate disposal. However, some types of solid wastes have been processed for the recovery of valuable constituents prior to the ultimate disposal of the remaining material. Such wastes have usually been processed to recover or produce any one or more of the following types of products: (1) Products that are recycled to the operation from which the waste material originated; (2) Products that serve as raw materials for manufacturing operations; and (3) Products that are utilized directly.

The scope of the commercial application of physical beneficiation unit processes to the treatment of such wastes is indicated in Table 8.

Furlow and Zollinger have described a proposed system for the disposal of municipal garbage and refuse that features the recovery of nonferrous scrap, ferrous scrap, aluminum scrap, glass, plastics, rubber, rags, and paper by hand sorting and magnetic separation.[145] A diagram of the plant is shown in Figure 5.

Roughly 20 percent of the waste tonnage processed would be removed in the salvage section by hand sorting. Four successive selection conveyors would be employed in this section for the salvage of various solid materials. Cardboard, newsprint, kraft paper, and mixed paper would be shredded and baled after being hand sorted from the first selection conveyor. Rags, glass, plastics, miscellaneous nonferrous metals, and rubber would be hand sorted from the second selection conveyor into large salvage containers located on both sides of the conveyor. Light ferrous metals and tin cans would be removed from the delivery end of the second selection conveyor and from the third selection conveyor by magnetic belt separators. The separator of each of these selection conveyors would be equipped with a strong electromagnet and a belt oriented at right angles to the direction of refuse movement. Heavy ferrous metals would be removed from the refuse stream by a magnetic head pully located at the discharge end of the third selection conveyor. The final step in the reclamation of solids from the waste stream would involve the hand sorting of aluminum cans and containers from the fourth selection conveyor. The remaining waste would then be processed through the preparation, digestion, and finishing steps, which are in experimental stages.

THE SCRAP METALS INDUSTRY

The reclamation and utilization of nonferrous scrap metals is an old and well established industry engaged in a multimillion-dollar business annually. Thousands of dealers, smelters, and refiners have been strategically located throughout the United States to collect and process scrap metals and metal-bearing products. A partial list of such companies is presented in the 1966 edition of *Metal Statistics*.[4] It illustrates the geographical distribution of firms and the kinds of scrap materials with which those firms deal. Several of the companies listed also operated mines, smelters, and refineries internationally, and some had more than one plant in the United States for the treatment of nonferrous scrap metals. A number of foreign buyers are included in the list. The *Waste Trade Directory* contains a complete list of scrap-metal processors arranged geographically and according to kinds of metals processed.[5]

The major conclusions drawn from the study of nonferrous scrap are:

(1) The large number of dealers and processors for gathering, preparing, smelting, refining, and marketing scrap metals assures much competition and consequently promotes

TABLE 8

THE COMMERCIAL TREATMENT OF INDUSTRIAL AND MUNICIPAL SOLID WASTES

Solid waste	Waste-producing industry	Waste-processing industry	Waste-separation process	Recovered useful products
Garbage and refuse	Residential, commercial, and industrial assemblages.	Municipalities	Hand sorting, magnetic separation.	Nonferrous scrap, ferrous scrap, glass, plastics, rubber, rags, paper.
Waste wood	Pulp	Paper	Gravity separation (by heavy media).	Wood, bark.
Bark	Pulp	Fertilizer	Screening	Sized bark.
Bagasse	Sugar	Paper	Screening	Bagasse fiber, pith.
Wastepaper	Residential, commercial, and industrial assemblages.	Paper	Hand sorting, gravity separation (by cyclones), mechanical sorting, screening, magnetic separation, flotation.	Paper fiber.
Grinding wastes	Tool		Gravity separation (by heavy liquids), flotation.	Diamonds.
Fly ash	Electric power	Electric power	Magnetic separation, air classification, screening.	Ferropozzolan, purified pozzolan.
Slag	Steel	Steel	Magnetic separation, screening.	Sized slag.
Foundry wastes	Foundry	Foundry	Magnetic separation, screening, gravity separation (by shaking tables), air classification.	Molding sand, metals, alloys.
Nonferrous metal scrap.	Atomic power, electric power, automobile.	Atomic power, electric power, automobile.	Magnetic separation, screening.	Alloys, metals.
Nonferrous metal residues.	Smelting	Smelting	Screening, gravity separation (by jigs and shaking tables), air classification, heavy-media separation.	Metals.

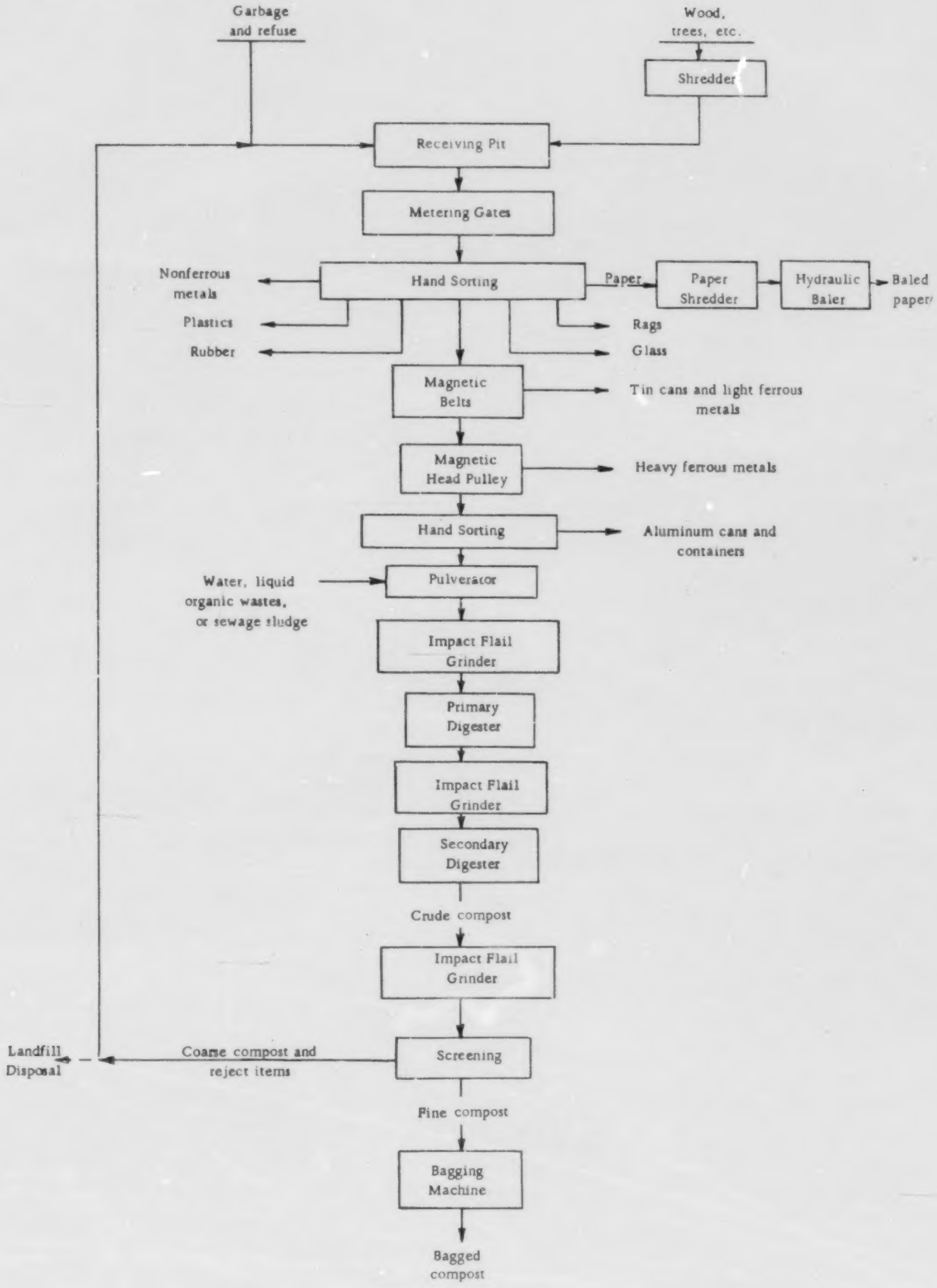
Garbage and refuse
Wood, trees, etc.
Shredder
Receiving Pit
Metering Gates
Hand Sorting
Nonferrous metals
Plastics
Rubber
Paper
Paper Shredder
Hydraulic Baler
Baled paper
Rags
Glass
Magnetic Belts
Tin cans and light ferrous metals
Magnetic Head Pulley
Heavy ferrous metals
Hand Sorting
Aluminum cans and containers
Water, liquid organic wastes, or sewage sludge
Pulverator
Impact Flail Grinder
Primary Digester
Impact Flail Grinder
Secondary Digester
Crude compost
Impact Flail Grinder
Screening
Coarse compost and reject items
Landfill Disposal
Fine compost
Bagging Machine
Bagged compost

FIGURE 5. *The reclamation of municipal refuse by the SACS process.*

efficiency in reclamation and utilization.

(2) Because of the efficiency of the industry, large tonnages of new scrap metals generated in manufacturing operations by major companies are transferred to secondary processors to produce marketable metals.

(3) The operations to produce marketable metals are complex, and they require special skills, expensive facilities, and knowledge of metal marketing. They must be conducted in reasonably large scale to be competitive.

(4) The recovery and refining operations are much simpler and hence less expensive when different types of materials are treated separately instead of as mixtures.

Quantities of scrap returned to industry. The United States Bureau of Mines compiles and publishes statistics regarding the recovery in the United States of the major nonferrous scrap metals. These data may be found in *Minerals Yearbook*.[5] The Bureau of Mines, as well as the industry in general, has differentiated between "primary" and "secondary" production of metals. "Primary" production derives metals from ores and concentrates, while "secondary" production derives them from scrap metals and industrial by-products. The term "new scrap" has been used to designate cuttings, turnings, and other waste materials generated during the fabrication of equipment and merchandise. "Old scrap" refers to parts of obsolete equipment and to piping, wire, and other materials reclaimed in dismantling buildings, ships, and the like.

The *Minerals Yearbook* for 1964, Volume 1, contains information regarding the activities of secondary producers of metals and the tonnages of products. The data in Table 9 were abstracted from that publication to show the magnitude of the secondary-metals industry.

Kinds of nonferrous scrap metals and materials. The referenced data on the quantities of industrial scrap metals showed a number of classifications for the materials processed and the products obtained. Actually, there are many more classifications of nonferrous scrap metals. The National Association of Secondary Material Industries, Inc., has issued Circular NF-66, "Standard Classification for Non-Ferrous Scrap Metals", which contains standard classifications for 119 types of nonferrous scrap metals.[318]

Precious metals have been recovered from a variety of materials, including photographic film and solutions. Parry presented the list of such materials in an article published in 1962 (Table 10).[340]

Recovery of the less common metals has also been important industrially as evidenced by literature describing plants and operations.

See also: Nonferrous Scrap; Precious Metals.

Prices of scrap metals. Four categories of nonferrous scrap materials have been particularly important because of the large tonnages involved. Scrap aluminum, copper, lead, and zinc have been sufficiently important industrially to warrant daily publication of prices for the more common types of scrap containing those metals. Table 11 lists the scrap-metal prices for August 16, 1966, given in *American Metal Market.* It illustrates the price differentials for the various types of copper, lead, zinc, and aluminum scrap.

Sources of scrap metals. Most of the nonferrous scrap metals returned to industry have been obtained from industrial plants that generally have not processed their scrap metals for reuse. Plants that generate large amounts of scrap metals may have contracts with wholesale dealers for the collection of those metals. The remainder of scrap metals has been brought to dealers by collectors from sources such as small shops and municipal refuse collection. The dismantling of obsolete machinery and buildings has also provided a source.

Examples of the reclamation of scrap metals on a large scale by a major manufacturer and on a modest scale by a municipality have been described in recent publications. An article of January 1966 described equipment used to collect 150,000 pounds daily of aluminum chips from profiling operations.[516] Problems resulting from the accumulation of scrap aluminum at the source were eliminated by installing at each profiler a Torbit separator to gather the continual flow of metal particles. The publication stated that the sale value of the scrap aluminum was increased noticeably by the chip-collecting system because contamination of the product was prevented by continuous removal of the chips from the profilers.

Sanders has furnished information

TABLE 9

NONFERROUS SCRAP RECOVERED IN THE UNITED STATES IN 1964[5]

Type of scrap	Weight recovered, thousands of tons
Aluminum	552. 0
Antimony:	
Antimonial lead	22. 3
Secondary smelters	20. 8
Primary smelters	0. 3
Copper, alloyed and unalloyed (73 to 90% as much as domestic mine output, 1955-64)	1093. 0
Secondary lead	541. 6
Magnesium alloys	10. 0
Mercury (76-lb flasks)	0. 9
Nickel	23. 0
Tin	23. 5

TABLE 10

PARTIAL LIST OF PRECIOUS METAL SCRAP [34]

Type of scrap
Turnings, chips, shavings.
Silver on steel bearings.
Silver steel turnings.
Grindings.
Blanking scrap, stampings, strip, and wire.
Powder mixtures.
Screen scrap.
Solder scrap.
Brazing alloy scrap.
Contact alloy scrap.
Silver on steel, tungsten, and molybdenum scrap.
Bimetal scrap.
Silver-paint waste, wipe rags, paper, and cans.
Old batteries.
Plating solutions.
Precipitates, sludges and sediments.
Coated copper wire and racks.
Filter pads.
Anode ends.
Tank scrapings.
Electrolytic silver.
Hypo solutions.
X-ray film.
Coated plastics, ceramics, glass, mica, quartz, etc.
Chemicals.
Mirror solutions($NaNO_3$).
Platinum-bearing material.
Gold on molybdenum or tungsten wire.

TABLE 11

SCRAP METAL QUOTATIONS FOR AUGUST 16, 1966—CARLOAD LOTS DELIVERED TO BUYER'S WORKS [a]

Type of scrap metal	Wholesale buying price, cents (or dollars, where indicated)	
REFINERS' COPPER SCRAP [b]		
Copper:		
No. 1	44. 00	
No. 2	39. 00	
Light	35. 50	
Refinery brass [c]	32. 00	
BRASS-INGOT MAKERS' SCRAP [b]		
	East	Midwest
Copper:		
No. 1	44. 00	44. 00
No. 2	39. 00	39. 00
Light	35. 50	36. 00
No. 1 composition solids	37. 00–37. 50	36. 00–36. 50
Composition borings, turnings	36. 00–36. 50	35. 00–35. 50
Radiators	26. 00–26. 50	26. 00
Yellow brass:		
Solids	25. 00	24. 00
Turnings	21. 00	21. 00
SMELTERS' SCRAP LEAD		
Battery plates: Smelting charge per ton (East) dollars	[d] 70.00–75.00	
Clean, heavy soft lead cents	12. 75–13. 00	
Cable lead:		
Lead content [e] do	12. 75–13. 00	
Copper content [e] do	[b] 38. 50	
SMELTERS' SCRAP ZINC		
New zinc clippings	10. 50–11. 00	
Old zinc (clean)	8. 00–8. 75	
Old die cast (clean basis)	7. 50–8. 00	
Die-cast slab (92% minimum)	10. 15–11. 20	
Dross galvanizing	10. 75–12. 00	
Dross; continuous mill	9. 80–11. 00	
Zinc skimmings [f]	Up to 3. 75	
SMELTERS' SCRAP ALUMINUM		
Aluminum clippings:		
3003 ^{35}	16. 00–16. 50	
6151 ^{515}	16. 00–16. 50	
1100 ^{25}	16. 00–16. 50	
5052 ^{525}	16. 00–16. 50	
2014 ^{145}	15. 00–15. 50	
2017 ^{175}	15. 00–15. 50	
2024 ^{245}	15. 00–15. 50	
7075 ^{755}	13. 00–13. 50	
Aluminum clippings (mixed)	14. 50–15. 50	
Old aluminum cast, including clean crankcases, pistons	12. 00–13. 00	
Aluminum borings and turnings, clean dry basis, less than 1% zinc, 1% iron content	12. 50–13. 50	

[a] Source: "American Metal Market," August 17, 1966.
[b] Nominal.
[c] For dry copper content guaranteed in excess of 60%.
[d] 60.00–62.50 dollars in Chicago, based on 14.80 cents in St. Louis.
[e] Less 30.00 dollars handling charge.
[f] Basis sample.

concerning the collection of scrap by the Light, Gas, and Water Division of the City of Memphis.[392] He emphasized the importance to profitable salvage operations of the conversion of scrap into forms that bring the highest prices. In 1963, scrap brass from light bulbs and other sources were sold to dealers for $3,500. Coils of insulated copper wire, lengths of lead-covered cable, and leaded copper connectors were heated to destroy the insulation and to separate lead from copper by melting the lead below the melting point of copper. About 87,000 pounds of lead and 262,000 pounds of copper were salvaged in 1963 by the utility division of the City of Memphis.

See also: Slag.

Marketing scrap metals. Scrap metals have been sold by dealers to wholesalers and to smelters. The value of the scrap and whether a specific kind of scrap will be sent to a primary or a secondary smelter depend on the proximity of the smelters, together with other considerations. The most important factor is the composition of the scrap in desirable metals and undesirable metals or foreign materials. The composition influences the expenses for transporting, sorting, sampling, preliminary treating, smelting, and refining.

PREPARATION OF SCRAP METALS

Nonferrous scrap materials frequently require treatments to prepare them for melting, smelting, and refining operations. Turnings, borings, and punchings of new metals may be subjected to magnetic separation to remove iron or steel fragments. In some instances, degreasing has been practiced to overcome the adherence of the ferrous contaminants to the turnings and borings. Stripping machines or manual methods have been used to remove lead sheathing and insulation from electrical cables. Materials that are not entirely metallic, such as sweepings, drosses, ashes, and slags.

may be ground to liberate metallic prills, drippings, and grindings. The liberated metallic particles can then be recovered by physical methods of separation based on differences in specific gravity or other physical properties.

If the source of a particular lot of scrap metal is known, the lot can be sold without analysis. Mixed materials of uncertain origin must be sampled and analyzed to provide a basis for payment. These operations add to the expense of the transactions, but they can be minimized or avoided by careful segregation or sorting of scrap metals.

Scrap metals acquired by dealers have been sorted piece by piece by workmen who have attained great skill in identifying the many types of metals and alloys encountered. The sorting process has frequently been repeated at the smelting plant. The surest and simplest means for identifying scrap is by knowledge of its use or origin. Thus, plumbing fixtures, copper wire, automobile radiators, and lead battery plates are easily distinguished, even by only slightly experienced people.

Less obvious metallic articles may be subjected to tests depending on specific physical and chemical properties of metals and alloys. Pieces may be tested with a magnet to help identify steel with nonferrous coatings and certain bronze and nickel alloys. Filing and drilling are used to determine the relative hardness of pieces, and the freshly exposed surfaces of metals may be noted for color and texture as an aid in classification. A number of spot tests with chemicals have been developed for rapidly identifying metals or alloys. These tests make use of characteristic colors, gassing, or formation of precipitates when reagents are dropped on metallic surfaces. Well-equipped laboratories for chemical analyses are adjuncts to some scrap-handling plants. They are used to identify and analyze scrap for purposes of classification as well as for the control of smelting and alloying processes.

Kobrin has discussed the influence of identifying and segregating types of scrap on the profitability of secondary-metals recovery.[298] He claimed that dealers were being confronted with greater amounts of such materials as beryllium-copper, Inconel, titanium, and precious metals. When scrap is properly segregated, it can be directed back to specific mills. Therefore, developing special techniques and equipment to identify, sort, process, and package scrap is a vital phase of the business, according to Kobrin. One sorting technique he described was based on the marked effect of certain impurities on the hardness of titanium. Hence, Kobrin stated, Brinell hardness tests can be used to segregate various grades of titanium scrap.

An example of the use of grinding to free scrap metal from glass is given in another article by Sanders on the salvage shop of the Light, Gas, and Water Division of the City of Memphis.[363] He described the use of a rotary drum crusher, which treated 89,000 light bulbs in 1 year. The grinding drum was filled with light bulbs and several chunks of scrap iron. Rotation of the drum ground the glass free from the metallic ends.

Bulky materials (e.g., wire, turnings, thin plates, sheets, and radiators) have been baled by compression in hydraulic presses to facilitate handling and charging the materials to furnaces. Compaction of small pieces also promotes heat transfer in the furnaces and minimizes losses of metals by oxidation and by entrainment of metal particles in slags. In contrast to the requirements for massive charge materials in furnacing processes, chemical methods require the large surface areas of particulate materials for the most efficient reaction. Therefore, in contrast to baling or briquetting of fine particles, it may be advantageous to grind or shred materials when chemical processes are employed.

It frequently is necessary to expel moisture from scrap metals simply to guard against explosions upon contact with hot materials in the furnaces. Conventional dryers, fired directly with the most readily available fuel, have been used.

PRODUCTION OF MARKETABLE METALS FROM SCRAP MATERIALS

The production of metals as marketable ingots, bars, pellets, or other shapes and forms from scrap materials is discussed here according to the major unit operations employed. The operations vary from simply melting scrap metal in a heated vessel preparatory to pouring the molten product into molds to form appropriate solid shapes, to complex combinations of hydrometallurgical and pyrometallurgical procedures.

Melting. The simplest operation for bringing scrap metals into salable forms has been to melt them and then cast them into convenient shapes for handling industrially. This can be done with metallic scrap that has been sorted and otherwise prepared so that the metal or alloy will be of a marketable composition.

The terms "melting" and "smelting" are frequently used interchangeably. However, simple alteration from a solid to a liquid, usually by heating, is considered "melting". "Smelting" refers to melting or fusing, and is usually applied to ores, with accompanying chemical changes to separate metals or compounds of metals from other constituents of the ores or charge materials. In general, however, plants that produce secondary metals by furnacing operations are called smelters. The nonferrous-scrap industry employs various kinds of conventional equipment for melting, depending on the properties and the quantities of the materials to be melted.

Indirectly Fired Kettles and Crucibles. Heated kettles or pots can be used to melt magnesium, zinc, and the so-called white metals (alloys of tin or of lead), because these materials melt at relatively low temperatures. Kettles for this purpose have been made in essentially hemispherical shapes from cast iron or welded steel. They are mounted in refractory furnaces in such a manner that their contents are exposed to view and so that fuel oil or gas can be burned in the space under the kettles. Kettles have been available in sizes to hold any desired tonnage up to 100 tons or more.

The same method of indirect heating has also been employed on a much smaller scale to melt gold, silver, or alloys of the precious metals. For this purpose, a ceramic crucible of perhaps 25-pound capacity is used instead of a metallic kettle because the temperature required to melt the precious metals is too high for use of iron or steel vessels. Crucibles of larger sizes are used widely in the scrap-metal industry to melt alloys of copper, lead, zinc, aluminum, and other metals.

Equipment to melt metals in crucibles has been manufactured by a number of companies. The heat may be supplied by burning fuels or by the consumption of electrical energy. Some of this equipment has been designed to permit tilting of the crucible or the entire furnace to pour the molten metal. High-frequency induction furnaces belong in this category. They have been used extensively for melting precious metals that are treated in relatively small amounts.

Ordinarily, little or no obnoxious smoke or fume is produced from the kinds of melting equipment described above. The reason for this—in the case of melting kettles—is that the melting is conducted at temperatures too low to volatilize metals or their compounds and that the gaseous products of combustion do not come in contact with the charge material. The usual small scale of operation with indirectly heated crucibles generally does not produce much fume or smoke.

Melting and refining. In the majority of cases, scrap metals require some refining after melting, even though the scrap was carefully sorted and prepared for melting. The refining treatment may consist of simply skimming dross and slag from the surface of the molten bath, or it may involve successive treatments with reagents to remove one contaminant after another. Several types of internally fired furnaces have customarily been applied for the melting and refining of scrap metals.

The reverberatory types of furnace, stationary and rotary, produce the major portions of secondary metals. It has been estimated that most of the brass and bronze ingots consumed by industry originated from the treatment of scrap materials in reverberatory-type furnaces. Large amounts of aluminum, lead, and zinc metals and alloys have also been produced with such furnaces.

Reverberatory Furnaces. A reverberatory furnace is a rectangular enclosure, usually lined with magnesite brick, with openings in the sides or the roof for receiving charge materials. Skimming doors are installed in the side walls of the furnace to remove slag or dross, and tap-holes extend through the refractories at several levels above the furnace bottom for skimming slag and for draining the molten metal product. Burners for the combustion of oil or gas are inserted through one end of the furnace and a flue for exhausting the products of combustion is provided at the opposite end. The heat from the combustion is transferred directly to the charge by radiation and conduction. "Reverberatory" refers to the reverberation or radiation of heat from the roof of the furnace onto the charge or bath in the furnace. The reverberatory type of furnace which has probably been the one most commonly used in the secondary-metal industry has been used almost exclusively for the primary smelting of copper, and the open-hearth furnaces used for steelmaking can be classified as reverberatory furnaces. Reverberatory furnaces can be designed and erected, in sizes to suit various needs, by a large number of engineering and construction firms. The capacities of furnaces used in the secondary-metals industry have ranged from as little as 1 ton to about 150 tons.

See also: Aluminum; Copper; Lead.

Rotary Furnaces. A rotary furnace consists of a refractory lining in a steel shell that resembles a cylindrical rotary kiln. Magnesite brick is the usual refractory lining material. The steel cylinder is surrounded by riding rings, which run on steel rollers mounted on piers. Burners are attached at the end of the furnace, and an opening is provided in the side of the cylinder. Charge materials are introduced through the opening. Slag and metal are skimmed or drained by rotating the furnace to bring the opening to any desired level. Rotary furnaces are commonly supplied by companies engaged in the erection of smelting equipment. The capacities of single units may be from about 1 to 50 tons.

Rotary furnaces operate in the same manner as reverberatory furnaces, that is, by internal combustion of fuel in the space above the charge material. Some metallurgists favor rotary furnaces over stationary reverberatory furnaces because heat transfer and coalescense of prills of metal are promoted by the ability to mix the charge by rotating the furnace. Rotation of the furnace also enables the operator to pour the molten contents conveniently.

Smelting and refining. Smelting involves chemical changes in conjunction with melting or fusing of materials. The chemical changes generally consist of reduction or dissociation of oxides or other compounds to form metals, and the formation of slags. Ordinarily, it has not been possible to make the chemical reactions so selective that only one metal is produced in smelting. Consequently, it has generally been necessary to refine the metallic products from smelting operations to obtain separate marketable metals.

Schedules for purchasing ores and concentrates have been developed and are widely used, especially by the companies engaged in the primary smelting of copper, lead, and zinc. Although such schedules are intended for ores and concentrates, they may be informative to producers of nonmetallic products that require smelting and refining. Salsbury *et al.* presented data that can be used to survey available markets and to make preliminary estimates of the return to be expected from an ore.[391]

Reverberatory types of furnaces may be used for smelting and refining. Blast furnaces also are employed for smelting nonferrous scrap materials.

See also: Aluminum.

Blast Furnaces. Blast furnaces consist of vertical shafts. They are charged at the top with a mixture of metal-bearing materials, fluxes, and coke. The coke is burned in air supplied through tuyeres placed near the bottom of the shaft. A crucible and tap holes are positioned below the tuyeres. The crucible serves as a reservoir for the molten materials, which descend through the incandescent coke at the tuyere level. The molten products are removed periodically through the tap holes.

Oxygen enrichment of the air supplied in blast-furnace smelting of scrap materials has been adopted and substantial benefits have been claimed from this practice when applied to charges of battery plates and lead drosses.

Blast furnaces can be erected in a variety of sizes, and the smaller sizes can be obtained as complete units ready to install on foundations. A somewhat typical furnace, which has been described in the literature, measures 6 feet by 3 feet by 10 feet deep. That furnace is water jacketed and has six tuyeres on each long side of the furnace. The water-jacketed type of construction has been most common. It has the advantage that a shell of solidified slag forms on the water-jacketed walls of the shaft to take the place of refractories. The crucibles of blast furnaces have ordinarily been formed of basic refractories.

An article published in the *Engineering and Mining Journal* describes advantages for an unusual method of constructing a blast furnace for smelting copper scrap.[536] It states that the capacity for smelting a copper scrap was increased from 35 to 100 TPD of charge material. At the same time, coke consumption dropped from 25 to 10 percent of the charge. These benefits resulted from inverting the bosh of a blast furnace; that is, from increasing rather than decreasing the cross-sectional area of the furnace shaft at the tuyere line. The lowest grades of scrap, consisting of irony brass, sweepings, ashes, skimmings, residues, radiators, wire, grindings, powders, cuttings, chips, and clad materials, were smelted in this furnace.

Blowers to supply the air blast and pumps to furnish the cooling water may be of the positive-displacement or the centrifugal types. Ladles and slag pots are needed to receive and to convey the molten slag and metal products. The gaseous products from the tops of blast furnaces have contained too much fume to be expelled directly to the atmosphere; hence, the top gas has been passed through bag houses or scrubbing plants.

The use of blast furnances for secondary smelting has been confined mostly to the treatment of materials containing lead or copper. The relationship between reverberatory furnaces and blast furnaces in the smelting of battery plates and lead drosses were discussed in connection with the uses of reverberatory furnaces. Blast furnaces have generally been employed for smelting the poorer grades of copper-bearing scrap because the process can reduce copper from its oxides and it can produce copper relatively free from contaminants. The product from a copper blast furnace, called black copper, however, contains small but objectionable amounts of antimony, bismuth, tin, lead, zinc, and nickel. Such material requires electrolytic refining.

See also: Copper; Slag.

Distillation. Distillation has been employed to reclaim metals having low boiling points from scrap materials. Several types of furnace have been in general use, but their essential features are similar. The larger furnaces, for the distillation of scrap zinc, have been refractory-lined chambers surrounding bottle-shaped retorts made of molded refractory materials. Either gas or oil has been burned in the furnaces to supply heat through the walls of the retorts. Retorts usually hold about 4,000 pounds of scrap which may be charged as solid or molten metal.

Distilled zinc may be condensed to a molten form or to zinc dust. A condenser consisting of a steel shell lined with refractory has been used for producing molten zinc. It is attached to the retort and protrudes from the furnace. The usual dimensions of a condenser are about 8-foot length and 3-foot diameter. The product is withdrawn through a tap hole in the condenser and cast into slabs for marketing.

Unlined steel condensers have been used to produce zinc dust. They may be 8 feet long, 7 feet wide, and 14 feet tall. The product from such condensers has been screened to yield dust containing 96 percent metallic zinc with 96 percent of it as minus 325-mesh particles.

Retort Furnaces. Retort furnaces have been used to produce zinc metal from zinc dross, zinc die castings, new and old zinc scrap, and similar types of scrap that contain mostly zinc. Lower grades of materials and nonmetallic materials are preferably processed at primary smelters. Retort furnaces have been employed to separate the more valuable metals such as zinc, cadmium, and mercury, from silver.

Slag Fuming. The process known as "slag fuming" is a form of distillation because it utilizes the high vapor pressure of metallic zinc at elevated temperature. Initially, it was applied to recover zinc as zinc oxide from molten slag while slags were being produced. The process was also used to reclaim zinc from slags rejected to waste dumps before the fuming process was invented. It depends on the reduction of the zinc compounds in slag by reaction, either directly or indirectly, with carbon injected into the molten slag.

Pulverized coal suspended in air is blown into the molten slag contained in a rectangular furnace of water-jacketed construction. The mixture of coal and air is introduced through tuyeres placed near the bottom of the furnace. The method causes violent turbulence of the slag bath. The coal not only provides for reduction of the zinc, but also for generation of heat. The coal requirement has been about 20 percent of the weight of the slag; about 2 hours of blowing time has been required to eliminate the zinc from a batch of slag. Slag quarried from old dumps can be charged with molten slag from smelting furnaces. The ratio of cold slag to molten slag and the ratio of coal to air has been controlled to maintain the temperature in the furnace at about 2,200° F.

The mixture of zinc vapor and carbide monoxide expelled from the slag bath is oxidized in the space above. Then the gaseous mixture containing zinc oxide passes through coolers and bag filters. The product from the bag filters has normally contained about 70 percent of zinc and about 8 percent of lead. It is densified, and most of the lead is expelled by heating in rotary kilns at about 2,300° F. with additions of about 2 percent of fine coke. This treatment increases the density of the zinc oxide from about 40 to 185 pounds per cubic foot and provides a product containing about 1 percent of lead. Most of the zinc oxide produced by slag fuming plants has been transported to electrolytic zinc plants for recovery of the zinc as metallic zinc.

Hydrometallurgical processes. A number of hydrometallurgical processes involving operations such as dissolution, precipitation, cementation, filtration, and electrodeposition have been employed in the recovery and utilization of metals from scrap materials. In many cases the methods are combinations of familiar steps commonly used in separations for chemical analysis. The combinations, however, may be very complex, and they must be varied to suit the specific properties of the materials to be treated and the types of products desired. And in turn, the equipment for conducting the operations must be suited to those needs and to the reagents and other conditions of the operations.

See also: Copper; Germanium; Precious Metals; Pyrite Cinder; Uranium; Yttrium; Zinc.

REGULATIONS CONCERNING SOLID WASTE DISPOSAL

(Based on August 1966 Survey)

In the August 1966 survey of the State health departments, information was requested concerning regulations covering the disposal of solid wastes. Information contained in the following paragraphs was supplied.

In most States, the municipalities or counties have the authority to operate and control solid-waste activities. Ten[*] States did not have any legal authority in the matter of solid waste disposal, private or municipal. The legal authority reported by 13[†] States was based on general health or nuisance laws and on water and air pollution control laws. In Minnesota and Texas permits must be obtained from the water pollution control board when areas adjacent to waters of the state are used as waste disposal areas. It was pointed out that in Montana muds and sludges from mining are not a health hazard, so industries are left to themselves to work out disposal methods.

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[*] Arizona, Colorado, Georgia, Hawaii, Kansas, Maine, Missouri, Nevada, Washington, Wyoming.

[†] Alabama, Alaska, Arkansas, California, Idaho, Minnesota, New Hampshire, North Carolina, Ohio, Pennsylvania, Tennessee, Texas, Utah.

Depending on the situation, these safeguards may be required in order to obtain a permit in Minnesota: (1) Diking around the site (assuming the dike is sound); (2) diversion or containment of surface drainage; (3) sealing of previous soil or rock formations; (4) covering of dumped or stored material to minimize erosion and control drainage and storm-water percolation; (5) regular supervision and control of operations; and (6) provision of an alternate site disposal.

The following were listed as being subject to regulation because they are potentially deleterious or detrimental to public health: slaughterhouses, rendering works, glue works, depositories of dead animals, tanneries, wool-washing establishments, paper mills, by-product coke ovens, dye works, oil refineries, dairies, creameries, cheese factories, milk stations (Pennsylvania, Montana) and the burning of cotton-gin wastes (Texas).

Only six States had specific legislation providing authority for the State health departments to conduct a program for the control of the storage, collection, and disposal of solid wastes (Montana, Nebraska, New York, Oregon, South Dakota, Texas). In Texas this authority is specific for refuse deposited within 300 yards of a public highway. In Idaho legislation of this type has been proposed.

No routine testing was reported by any State for the detection of contamination of water by solid wastes deposited in spoil areas. It was indicated that normally routine stream surveys show whether pollution is occurring. If problems develop, the tests in Minnesota were generally highly specialized, as required by the nature of the problem. One State reported that tests were run in the vicinity of a spoil area used by an industry manufacturing insecticides. Samples were collected in test wells adjacent to the burial area (Tennessee). Observational wells have also been required before a permit was issued for an industrial waste disposal area (Texas). Tests have also been made for radioactive contamination of a well (Utah).

Water contamination, of course, is of special interest. The survey of State health departments revealed that a number of solid industrial wastes have contaminated State waters: (1) Forest industry and lumbering wastes, such as sawdust, bark, drainage from log ponds, and slabs (Alaska, Idaho, Minnesota, South Dakota); (2) runoff from mining wastes subsequent to leaching (Arizona, Nevada); (3) mining wastes (Georgia, Idaho, Minnesota, South Dakota, Texas); (4) pulp and paper sludge (Georgia, Pennsylvania); (5) sulfur from stockpiles (Minnesota); (6) calcium hydroxide from the manufacture of acetylene gas (Georgia); (7) potato-processing wastes, such as culls, and other potato wastes (Idaho); (8) animal carcasses (Idaho); (9) Meat-packing and rendering wastes (Texas); (10) metal refining wastes (Nevada); (11) metal finishing waste sludges (Pennsylvania); and (12) feed lot wastes (Texas).

In Texas, to prevent water contamination by feed lot wastes, facilities were required that would retain all runoff generated by a 2-inch rain from a waste disposal area.

In response to a question concerning the tests made to determine the stability of solid industrial wastes deposited in a spoil area it was revealed that generally the tests used to determine whether surface water or groundwater is being contaminated by solid industrial waste deposited in spoil areas depend upon the nature of the material deposited. Tests used in Texas include color, turbidity, dissolved oxygen, biochemical oxygen demand (BOD), and both ammoniacal and nitrate nitrogen. In addition, samples were analyzed for organic content by chromatography.

Current activities reported by states responding to the questionnaire included the following:

The Arkansas State Pollution Control Commission was designated the State agency for reviewing solid waste grant applications. No staff had as yet been obtained.

In California a statewide inventory was being made of sources, quantities, methods of disposal, etc., of all types of solid wastes.

In Idaho a planning grant had been obtained to study the solid waste problem, including solid industrial wastes. Also in Idaho, a regulation providing for State authority for control of refuse disposal had been proposed.

In Rhode Island in July 1966 a solid waste disposal program was established in the Division of Environmental Health. One of the main objectives of the new program was to determine the adequacy or inadequacy of existing solid waste disposal practices and the need for additional regulations for the enforcement of an acceptable statewide solids disposal program. No full-time personnel were working with industries or municipalities to help them with solid waste problems.

In Maine, the Division of Sanitary Engineering was gathering data with which to develop a statewide comprehensive plan for solid waste disposal. Municipal solid waste disposal was being studied. Solid industrial wastes might be studied at a later date.

A bill to give the Ohio State Health Department authority to regulate solid wastes was scheduled for introduction into the next session of the legislature. Ohio had obtained a grant under the Solid Waste Act (P.L. 89–272) for a survey of and statewide planning for solid waste disposal.

Major Waste Categories

Acetylene Wastes
Agricultural Wastes
Aluminum
Animal-Product Residues
Antimony
Asbestos
Ash, Cinders, Flue Dust, Fly Ash
Asphalt
Bagasse
Bauxite Residue
Beryllium
Bismuth
Brass
Brewing, Distilling, Fermenting Wastes
Brick Plant Waste
Bronze
Cadmium
Calcium
Carbides
Carbonaceous Shales
Chemical Wastes
Chromium
Cinders
Coal
Cobalt
Coffee
Coke-Oven Gas
Copper
Cotton
Dairy Wastes
Diamond Grinding Wheel Dust
Distilling Wastes
Electroplating Residues
Fermenting Wastes
Fish
Flue Dust
Fluorine
Fly Ash
Food-Processing Wastes
Foundry Wastes
Fruit Wastes
Furniture
Germanium
Glass
Glass Wool
Gypsum
Hemp
Hydrogen Fluoride
Inorganic Residues
Iron
Lead
Leather Fabricating and Tannery Wastes
Leaves
Lime
Magnesium
Manganese
Mica
Mineral Wool
Molasses
Molybdenum
Municipal Wastes
Nonferrous Scrap
Nuts
Nylon
Organic Wastes
Paint
Paper
Petroleum Residues
Photographic Paper
Pickle Liquor
Plastic
Poppy
Pottery Wastes
Precious Metals
Pulp and Paper
Pyrite Cinders and Tailings
Refractory
Refrigerators
Rice
Rubber
Sal Skimmings
Sand
Seafood
Shingles
Sisal
Slag
Sodium
Starch
Stone Spalls
Sugar Beets
Sugar Cane
Sulfur
Tantalum
Tetraethyllead
Textiles
Tin
Titanium
Tobacco
Tungsten
Uranium
Vanadium
Vegetable Wastes
Wastepaper
Wood Wastes
Wool
Yttrium
Zinc
Zircaloy
Zirconium

ACETYLENE WASTES

Acetylene wastes have been calcined and carbide made from the recovered lime. One plant was reported as having a capacity of 330 TPD.[186]

AGRICULTURAL WASTES

See also: Animal-Product Residues; Bagasse; Food-Processing Wastes; Fruit Wastes; Nuts; Slag; Sugar Beets; Vegetable Wastes; Wood Wastes; References 18, 21, 46, 47, 103, 156, 252, 279, 285, 300, 308, 315, 331, 341, 367, 395, 406, 437, 460, 473, 486, 430.

EXTRACTION

Carotene has been extracted from certain leaf meals for use as a feed supplement.[513]

HYDROLYSIS

The Soviet Union hydrolytic industry has produced large quantities of ethyl alcohol, 2-furaldehyde, carbon dioxide, acetic acid, activated charcoal coal, vanillin, trioxyglutaric acid and glucose from wood and agricultural residues.[260] The products and byproducts of agrarian residues were surveyed in 1956 by Wilder and Hirzel[474] and in 1952 by Goethals.[138] A continuous process for hydrolysis of wood and agricultural wastes was described by Desforges in 1952.[104]

The nature of reaction products from hydrolysis of cellulosic wastes was described by Heinemann.[183] The waste materials from hydrolysis can be used as a humectant in agriculture[422] and as fertilizer.[407]

The hemicelluloses that occur in association with cellulose have been used for large-scale production of furfural. They are hydrolyzed by sulfuric acid, which then dehydrates the liberated pentoses to form furfural. Corn stalks, flax wastes, sunflower stalks, fruit seeds or pits, bagasse, peach gum, nut shells, reeds, olive husks, and corn cobs are examples of residues that can be hydrolyzed to produce furfural.[44, 71, 78, 79, 113, 156, 157, 158, 212, 223, 270, 271, 330, 344, 386, 488]

The swelling rate of plant waste and its influence on the yield of furfural has been reported.[408] Acetic acid as a by-product of furfural production has been reported.[319] The residue from furfural production from sal bark, areca (palm) nut husks, and coconut shells, has been used as a filler for phenolic plastics.[318] Furfural can be readily converted to furan, tetrahydrofuran, hexamethylenediamine, and adipic acid for the synthesis of nylon; or to dichlorobutane, adiponitrile, E-amino capronitrile, and caprolactam for the synthesis of Perlon. Furan as the starting material for polyamide, polyurethane, alkyd and Buna-type resins, and rubber has been discussed.[98] Steps for the preparation of nylon from furfural are given by Voss.[471] Use of plant residues in the manufacture of plastics has been reviewed.[361, 436]

Alkaline digestion of the stems of rye and reed softens tissues to improve assimilability by ruminant animals.

ALUMINUM

See also: Recovery and Utilization; Reference 148.

SMELTER RESIDUES

Residues from aluminum smelting operations (drosses) are treated by a crushing-grinding-screening-classification operation for the recovery of the contained metallic aluminum. This aluminum is in the form of prills, shot, large spill splatters, etc., and is intimately mixed with or coated by slag. The aluminum metal, being malleable, resists crushing or grinding, whereas the slag is very fragile and breaks up easily. Consequently, this waste material is amenable to a differential crushing-grinding operation using screens or air classification equipment to effect the separation.

Hammermills are normally used for disintegration. Ball mills have been employed, but they tend to beat small particles of slag into the malleable aluminum. Any of the usual vibrating or shaking-type screens are suitable, as well as the normal type of air classifiers. The waste or dross treated will contain some 20 to 30 percent metallic aluminum. The product for return to furnaces should contain from 60 to 70 percent aluminum. Dusting is a problem in that up to 10 percent of the feed may eventually be dust. In addition, because of the friable nature of the slag, about 50 percent of the feed may finally be a relatively fine-size fraction (minus 20 mesh), which is not considered treatable because of the fine dissemination of the aluminum in the slag.

The beneficiation process is simple and reliable. It is relatively inexpensive, but no specific cost data were available. The recovered aluminum is generally melted in reverberatory-type furnaces, cast into pigs, and sold to consumers of metallic aluminum.

It has not been feasible to remove metallic contaminants, except magnesium, from molten aluminum scrap materials. Therefore, the producers of aluminum ingots from scrap have had to make salable products without benefit of refining. This has meant that the scrap could not contain excessive contaminants. Alloying metals may be added, however, to bring the composition of the product to specifications, or the contaminants may be diluted to acceptable levels by additions of purer metals or alloys.

See also: Recovery and Utilization; Reference 233.

ALUMINUM TURNINGS

Morken presented a comprehensive discussion of problems connected with the preliminary treatment of oily aluminum turnings.[310] The turnings or chips considered were produced at the rate of about 20,000 pounds per day by machining operations in an automobile plant. They contained about 21 percent of liquids present as oil and water. About 0.30 percent of uncombined iron, evidently abraded from cutting tools, was present as very fine particles adhering to the oily aluminum chips. It was imperative to remove the iron because the reclaimed aluminum was to be used for pistons.

Morken wrote that magnetic separation appeared to be the best method for removing the iron, but that this would require dried chips. The most economical and satisfactory procedure for drying oily chips appeared to be by use of a rotary kiln, directly fired with gas. The method in which heat input was controlled to vaporize rather than burn the oil minimized oxidation of the aluminum but caused much smoke. It was believed that, in addition to the smoke nuisance, the method of heating presented a severe explosion hazard. A number of experiments were conducted to remove oil by means other than heating. None of the experiments was satisfactory, according to Morken.

Eventually, Morken and his associates returned to thermal removal of the oil. It was learned that the drum-type dryer could be used without nuisance or hazard, provided the amount of oil on the chips was held reasonably constant. A process was developed in which centrifugal separators were used to remove oil to a content of 2.1 to 2.3 percent. This was done by flushing the chips in a centrifuging basket with cold water and then admitting 90-psi steam for about 2 minutes.

The flow of aluminum chips through the reclaiming facilities was described by Morken as follows. The incoming oily chips were received in skid boxes, which were dumped into a conveyor system containing magnetic separators to remove tramp iron. The conveyor deposited the chips in a surge hopper, which fed two centrifugal separators. After centrifuging, the chips were conveyed pneumatically to the drum dryer. The dryer discharged into a bucket conveyor, which fed a double-deck vibrating screen. This screen removed particles less than 30 mesh in size because it was considered uneconomical to recover this fine material. The screen oversize was discharged onto a magnetic separator from whence the cleaned chips were conveyed to melting furnaces.

Evidently, considerable thought and experimentation was required to devise the successful process for the preparation of aluminum-scrap outlined in the foregoing paragraph. It is interesting that the solution came from the judicious selection of a proper combination of well-known types of equipment and machinery.

See also: Separation.

REVERBERATORY FURNACES

Reverberatory furnaces have been preferred for melting aluminum scrap. Ordinarily a layer of flux has been used to protect the surface of the molten aluminum from oxidation. The flux may consist of sodium chloride, potassium chloride, and cryolite. Calcium chloride and sodium fluoride also might be used. Chlorine gas may be bubbled through the molten bath to combine with magnesium if it is necessary to eliminate that element. Nitrogen is introduced as a refining agent to expel dross and oxides from the metallic baths of aluminum.

See also: Recovery and Utilization.

DRYING

A rather common preparatory treatment is simple drying. It frequently is necessary to expel moisture from scrap metals to guard against explosions from contact with hot materials in furnaces. Conventional dryers, which are fired directly with the most available fuel, are used for drying scrap materials.

EXTRACTION

Furnace wastes from the manufacture of aluminum are extracted to recover fluorine, sodium, and aluminum compounds.[123, 250]

MAGNETIC SEPARATION

Morken also described how the piston foundry of the Chrysler Corporation recovered aluminum metal from oily aluminum turnings by magnetic separation and screening.[310] The aluminum recovered was eventually melted, cast into ingots, and recycled to the foundry. The quantity of aluminum recycled was sufficient to provide about 60 percent of the metal required by the foundry for piston manufacture.

Chapman has described how the Duke Power Company of Charlotte, North Carolina, employed magnetic separation to recover aluminum metal from strands of steel and aluminum wire.[70]

See also: Separation.

SINTERING

Fe-Si-Al-Ti alloys were produced from red mud from aluminum oxide preparation in an arc furnace.[179]

ANIMAL-PRODUCT RESIDUES

Several industries including soap, leather, glue, gelatin, and animal feed manufacture, have been based on meatpacking waste products. Biochemicals have also been produced from packinghouse residues. Freezing these wastes has largely overcome shipping and storage problems.

EXTRACTION

Biochemicals extracted from packing house materials include hormones, vitamins, enzymes, liver products, bile acids, sterols, feed supplements, and glandular products. Glands and organs have been collected and preserved by freezing until shipment lots accumulated.[523] Curing, evaporation, and extraction are involved in coverting the collagen in hide trimmings, tannery fleshings, etc., to gelatin and glue. Tallow has been produced by extraction of tankage.[263]

HYDROLYSIS

Hydrolyzates of materials of animal origin such as feathers, fish meal, meat, and fish residue can be used as animal feed ingredients.[167] The Twitchell method has commonly been used to obtain fatty acids and glycerine from fats by hydrolysis. A plant near Chicago has been reported to process 100 million pounds of fats and oils per year by this method.[264]

MECHANICAL SEPARATION

Inedible slaughterhouse materials have been passed through a grinding machine to a heating device, a cooking vessel, and a centrifuge to recover fat, meat, and bone scrap.[264]

MELTING

Bones have been autoclaved and treated with steam in the absence of oxygen. The proteins and fats obtained were separated and the purification completed by vacuum distillation.[178]

PYROLYSIS

Fuels and solvents can be manufactured by pyrolysis of waste products from the fat and vegetable-oil industries.[395]

ANTIMONY

See: Lead.

ASBESTOS

See: Plastic; Reference 284.

CALCINATION

Silica refractories are obtained by calcining asbestos waste and raw magnesite.[435]

INCINERATION

Asbestos wastes plus clay and binders are cast in plastic and fired to produce porous ceramics.[186]

ASH, CINDERS, FLUE DUST, FLY ASH

Fly ash has been described as a finely divided, powdery, man-made pozzolan composed of spheres of amorphous silica and alumina.[531] According to Russel, 8.25 million tons of it were produced in the United States in 1956 by pulverized-coal-fired boilers.[387] He further indicated that the annual domestic production of fly ash has been increasing since 1953 and could go as high as 16.8 million tons per year. Chemicals contained in coal ash include: cobalt, nickel, molybdenum, chromium, vanadium, tin, zinc, lead, arsenic, gold, platinum, palladium, silver, beryllium, gallium, lanthanum, silicon, aluminum, iron, manganese, magnesium, calcium, phosphorus, sodium, and potassium.

Approximately 1 gram of gold per ton is found in coal ash, but this is not an economic source because the chemical processing problems involved in recovery are extremely complex. The problems of enrichment and isolation of the separate chemicals have not been solved successfully.

Dumping is the easiest and most economical way of disposing of fly ash, but even dumping costs $1.00 per ton or $16 million per year, most of this to the utility companies.

Industry has found that not only is the disposal of fly ash expensive, but the areas available for its disposal are becoming scarce. Fly-ash disposal is a particularly annoying problem of major importance to the electric power plants that burn pulverized coal, since it is not uncommon for a single utility system to produce as much as a million tons of fly ash per year. The electric-power industry realizes that the solution to this problem lies in the large-scale utilization of the ash.

Most of the fly ash not disposed of by landfilling has been utilized directly without being processed. The following are some of the ways in which fly ash has been utilized: (1) In portland cement; (2) in mass structural concrete; (3) in masonry cinder and concrete building blocks; (4) in lightweight aggregate; (5) as a roadbase choking material for highway construction; (6) as a filler for bituminous mix; (7) as a filler material in roofing and putty; (8) as a soil conditioner; (9) as a soil stabilizer; (10) in oil-well grouting; (11) as a sand substitute in sand blasting; (12) as a metal-polishing agent and mild abrasive; and (13) as a filtering medium.

Recent research to improve knowledge of the characteristics and properties of fly ash has been described by Snyder.[419, 420]

See also: Incineration; Inorganic Residues; Reference 506.

COLLECTION

Katz stated that the various types of cyclone collectors are suitable for the collection of particles that are usually larger than from 5 to 10 microns in projected-area diameter.[27] Such collectors have been applied in series with the electrostatic precipitator, especially where large particles of carbon or grit predominate in the effluent gases. The installation of a cyclone immediately following the electrostatic precipitator would improve the overall collection efficiency of a system troubled by the severe reentrainment of highly conductive ash that agglomerates upon passing through the precipitator.

Katz indicated that the effective collection of fly ash by electrostatic precipitation depends primarily upon the electrical power input to the precipitator. The optimum power characteristics of the precipitator are determined by the electrical resistivity of the fly ash. This in turn is dependent upon the sulfur content of the coal burned in the plant, the temperature of the effluent gas, and the carbonaceous content of the fly ash. He stated that, "it is conceivable that by altering the coal burned, flue gas temperature, or the particle size distribution of the pulverizers, the plant operator could correct a sub-normal collector performance".

Magnus described the collection of fly ash at the South Charleston, West Virginia, power plant of the Chemicals Division of the Union Carbide Corporation.[273] The fly ash produced by the coal-fired boilers of this plant was collected by electrostatic precipitators at the rate of 328,000 pounds per day. About 36,850 pounds of fly ash were released daily to the atmosphere by the precipitators.

The problem of maintaining high collection efficiencies developed soon after the precipitators had been installed at the plant. The gas flow rate eventually proved to be the critical factor that had affected the achievement of the desired collection efficiency. It was also found that changes in the characteristics of the coal burned by the plant had a direct effect upon the operation of the precipitators. The plant has, however, been able to achieve precipitator collection efficiencies ranging from 93.2 to 95.7 percent.

TREATMENT

A process for the recovery of ferropozzolan and a fine purified pozzolan from fly ash by magnetic separation, air classification, and screening has been described in *Power*.[531] Fly ash was treated in a Roto-Flux magnetic separator by sieves, air separators, a battery of magnetized coils, and a conveyor belt to produce magnetic ferropozzolan, coarse purified pozzolan, and fine purified pozzolan. The separator could process 10 tons of fly ash per hour to produce a ferropozzolan containing from 50 to 70 percent of the iron oxide content of the original ash. Ferropozzolan has been employed as a heavy-medium material in heavy-medium separations and as a constituent of ferral cement for the manufacture of special dense mortars and concretes. The chief product of the separation is purified pozzolan, a high-strength product that is offered on the market on a certified quality-controlled basis. The Roto-Flux separator requires little space and costs about $15,000.

DISPOSAL WITH SEWAGE SLUDGE

Investigation of the possibility of disposing of fly ash with sewage sludge has shown that the material will dry to a nondusting mass requiring less disposal space than when the two are disposed of separately. Fly ash can also enhance the filtration of sludge.

ACIDIFICATION

The adsorption capacity of fly ash[374] and brown coal ash[138] is increased by treating these ashes with hydrochloric acid.

INCINERATION

By burning a mixture of coal ash with lime and sand, a binding material can be obtained that is similar to portland cement.[379]

ION EXCHANGE

Of three media—ion-exchange resins, cinders, and light ashes—light ashes are reported as giving the best removal of phenol from phenolic wastes. They decolorize the wastes as well.[326]

MELTING

Coal ashes, limestone, coal, and Fe_2O_3 have been melted to form $2Fe{\cdot}SiO_2$. The calcium aluminate slag has then been leached. The residue, after the addition of limestone, can be used in the manufacture of iron cement.[234]

SINTERING

Fly ash from a Long Island power station has been sintered and used as lightweight aggregate in cement.[478, 533] Germany also had a plant for making products from fly ash.[266] Blast furnace flue dust has been sintered and returned to the blast furnaces for smelting.[191]

VAPORIZATION

Flue dusts from the production of copper, zinc, and manganese have been processed for the recovery of arsenic and bismuth. In this process the dust is roasted, and the arsenic given off as a fume is condensed.[93]

ASPHALT

See: Reference 308.

BAGASSE

Bagasse is the fibrous residue that remains after the sugar juice has been pressed from sugar cane. It consists of about 30 percent pith, 10 percent water-soluble materials, and 60 percent good-quality fibers that range in length from 1.5 to 1.7 mm. These fibers are normally pulped following their separation from the nonfibrous pith cells, dirt, finely divided bagasse fibers, and weeds.

Bagasse is separated into fractions for applications that range from use as feedstuff to use as a raw material for high-grade-paper processing. When utilization schemes are not feasible, residues can often be burned

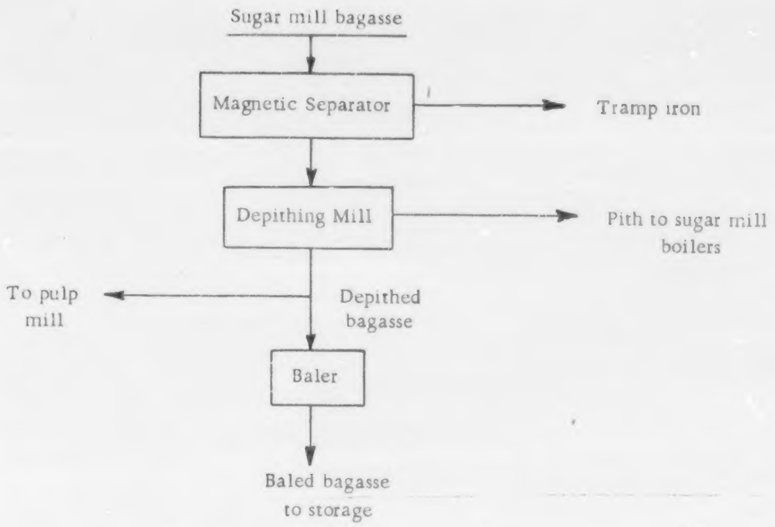

FIGURE 6. *Depithing of bagasse.*

to recover their fuel value. Charcoal and activated carbon can also be obtained from many of these materials.

Bagasse has frequently been burned as a fuel to produce steam required by the sugar mill for both power and processing. However, the pulp and paper industry has found that bagasse fibers are quite suitable for the production of insulation board, particle board, and almost any type of paper, ranging from bleached fine-quality writing and printing papers to unbleached wrapping papers and newsprint. The first pulp and paper mill to utilize bagasse as a raw material has been in operation for over 20 years. The construction of other mills was impeded for a time, however, by various technical difficulties. The development of new techniques about 10 years ago was soon followed by the construction of over 30 bagasse pulp mills throughout the world.

An annotated bibliography prepared by West describes the utilization of bagasse for paper, board, plastics, and chemicals.[480] Bagasse utilization has been summarized in three papers.[64, 281, 484]

See also: References 18, 22, 24, 42, 55, 78, 88, 92, 107, 155, 198–201, 212, 214, 253, 254, 266, 271, 283, 290, 299, 301, 302, 325, 401, 411, 443, 486, 488, 539.

DEPITHING

Bagasse fiber is usually prepared for paper pulping in a depithing station (Figure 6). Tramp iron entering the depithing station with the bagasse is first removed by a magnetic separator. Most of the pith is then separated from the bagasse fiber in a Horkel depithing mill. In this mill, the bagasse is first shredded by hammermills and then screened into separate fractions of pith and fiber. The separation is not a clean one, for the fiber still contains about one-third of the pith initially charged to the mill. A portion of the depithed fiber is shipped directly to the pulp mill for subsequent wet depithing and pulping with dilute caustic soda, while the remaining fiber is usually baled and stored for future use. The pith separated by the Horkel mill is returned to the sugar mill, where it is burned in the boilers as fuel. It is either transferred to the boilers by conveyors and bucket elevators or by blowers and cyclones. The bagasse and the depithed fiber are removed through the depithing station with conveyors.

HYDROLYSIS

Pulp for viscose rayon is produced by hydrolysis of bagasse.

See also: Agricultural Wastes; Vegetable Wastes; Reference 275.

INCINERATION

Whole bagasse is normally burned at 45 to 50 percent moisture in boilers having special furnaces. Steam is generated at between 100 and 150 psi. Oven-dry bagasse has a calorific value of about 8,200 Btu per pound. Bagasse with 50 percent moisture has a gross heating value of about 4,400 Btu per pound. An average of 1.2 tons of bagasse (moisture-free basis) is produced for each ton of cane sugar output.[100, 407, 487]

NITRATION

Nitrolignin is obtained from bagasse by nitration and digestion of the product.[214]

OXIDATION

A mixture of bagasse and coke is used in the reduction of nickeliferous serpentine.[32]

POLYMERIZATION

A plastic molding material called Valite has been produced by polymerizing aldehyde and ketone products of bagasse with phenol.[64]

SCREENING

The recovery of fiber from bagasse by screening has been mentioned by Martinez in connection with the utilization of bagasse for the manufacture of paper by the pulp and paper industry.[283]

BAUXITE RESIDUE

A mixture of bauxite residue and fuel that has been pelletized and sintered has been used as lightweight aggregate.[322]

BERYLLIUM

An electrolytic refining process is used to produce beryllium from scrap at Beryllium Metals & Chemical Corporation.[506]

BISMUTH

See: Lead.

BRASS

See: Copper; Foundry Wastes; Reference 390.

BREWING, DISTILLING, FERMENTING WASTES

The brewing, distilling, and fermentation industries are concerned with the production of alcoholic beverages, pharmaceuticals, and a limited number of organic chemicals. The principal solid waste from distilleries is stillage, the residual grain mash from distillation columns. In 1964, 630,000 tons were utilized. This material is recovered almost completely by the industry for animal feed or for conversion to chemical products. It has been reported that 85 percent of the stillage is recovered as dried feeds, 14 percent as wet feed, and only 1 percent is lost.

Some chemicals have been recovered from fermentation broths. Among them are d-lactone and l-lactone following calcium pantothenate production, vitamins and amino acids from fermentation wastes, bacitracin and amino acids from distillers' solubles, tartaric acid from wine residues, nicotinic acid from vitamin wastes, and glycerol from alcohol stillage.

See also: Food-Processing Wastes; Molasses.

CARBONIZATION

The ash of distillers' dried solubles has growth-stimulation properties according to Dannenburg.[93]

EVAPORATION

Brewery wastes have been evaporated and the residue used as feed.[312]

EXTRACTION

Tartrates, tannins, vitamin P-like compounds, potash, acetic acid, and other compounds have been produced from winery wastes.[491] Proteins are extracted from brewery residues and converted to plastics.[418]

HYDROLYSIS

Hydrolyzates from distillery sludge are sources of edible protein, deficient only in tryptophan and methionine.[308]

INCINERATION

Potash has been recovered by incineration of fermentation wastes.[373]

SCREENING

Spent grains after fermentation are almost universally removed on fine screens and are processed for use as cattle food. Eight to 10 pounds of this material can be recovered per bushel of grain processed. This by-product is an essential part of the industry's overall economy.

BRICK PLANT WASTE

INCINERATION

Brick-plant waste has been burned and exploded and used as building material.[337]

MELTING

Scrap brick, slag, and other industrial wastes can be melted and used to produce mineral wool.[340, 403]

BRONZE

See: Copper.

CADMIUM

See: Reference 249.

CALCIUM

See also: Lead.

COMBINATION AND ADDITION

Calcium sulfate sludge formed in the course of various manufacturing processes (e.g., from the working of potash salts, from the neutralization with lime of the sulfuric acid spinning solutions of the rayon industry, and in the manufacture of phosphoric acid from phosphates) can be simultaneously utilized with the ammoniacal liquors of cokeries and carbon dioxide to produce ammonium sulfate.[262]

CALCINATION

Modern (1949) methods for recalcining waste calcium carbonate have been surveyed by Knibbs and Gee.[234]

DISPLACEMENT

Silicon carbide has been prepared by extracting the calcium hydroxide from the furnace sediment formed during the manufacture of calcium carbide, mixing the remainder with carbon, and heating the mixture in an electric furnace.[230]

CARBIDES

Tungsten and cobalt have been recovered from scrap sintered carbides. The metals are oxidized with sodium nitrite as the first step in the recovery process.[61]

See also: Lead.

CARBONACEOUS SHALES

Humic fertilizer has been obtained from carbonaceous shales by nitration and chlorination.[229]

CHEMICAL WASTES

Chemical manufacturing plants produce solid wastes that are extremely varied in nature. Many toxic chemicals (e.g., phenol) can be destroyed by incineration. Occasionally, solid wastes from chemical plants can be utilized in some fashion, e.g., use of waste tar from alcohol preparation for a bitumen-type binder.

See also: Inorganic Residues.

CHEMICAL OXIDATION

A bitumen-type binder has been produced by oxidation of the waste tar from the preparation of synthetic alcohol.[124]

DILUTION

Effluent residues from conversion of paraffins into fatty acids can be diluted and used as a base for foundry binder.[37]

DISTILLATION

Most solvents can be reclaimed by distillation.[80, 276] Light oil and solvent can be obtained by distillation of spent straw oil from coke production.[60]

INCINERATION

Poisonous sediments and solutions containing phenols, waste oils, and the like can be destroyed by oil-gasification burners with special injectors, even when the moisture content is high or fluctuating.[401] Solid cyanide has been incinerated using waste solvent as fuel.[172] The incineration of solid wastes from tank-car cleaning has been described.[173]

Dow has a $2.25 million incineration plant that handles 81 million Btu/hr of liquid wastes and 60 million Btu per hour of solid wastes. Materials disposed of include 400,000 gallons per month of liquid still residues, washes, slurries, and other contaminated liquid products, 1700 drums and other containers of semiliquid and solid wastes per month; 17,000 cubic yards per month of other refuse, including large amounts of plastics.[537]

Lederle has incinerated rubbish, garbage, and valueless by-products from plant operations and sludges from sewage and waste-treatment operations. Iron, glass, and other noncombustibles have been removed by hand sorting.[171]

Industrial wastes have been incinerated at the Badische Anilin-Soda Fabrik plant.[144]

At Kodak Park, trash, waste solvents, oils, and various solid and liquid chemicals have been burned in an incinerator.[263]

Three wastes that have been incinerated even though auxiliary fuel is required for their combustion are a carbon waste slurry, a highly colored TNT waste, and a gas containing hydrogen sulfide.[69]

NEUTRALIZATION

Tailings in the production of hydrofluoric acid can be dry neutralized with calcium carbonate and used as an additive to control the setting of cements.[72]

CHROMIUM

Heating sludges containing chromium above 200° C. causes the chromium to convert to the poisonous chromate form.[370]

CINDERS

See: Ash, Cinders, Flue Dust and Fly Ash; Pyrite Cinders and Tailings.

COAL

See also: Lime; Reference 331.

CALCINATION

The carbonaceous pyrite in the residue from calcining wastes from grading of coal can be used to produce sulfuric acid.[472] Calcined wastes from coal mines can be used in the preparation of cement.[321]

DEHYDRATION

Charcoal of high discoloration power can be obtained from lignite by dehydration with sulfuric acid.[73]

INCINERATION

Coal washery refuse has been burned and used in the manufacture of concrete.[119, 204, 243] Carbon sludge from partial oxidation of fuel is disposed of by spraying it into a furnace for burning.[58]

MECHANICAL SEPARATION

There has been increased interest in reclaiming fine coals from coal processing waste waters. Both flotation techniques and use of cyclones and centrifuges appear to have merit for this purpose.

SINTERING

Disposal of tailings from coal processing is made easier by installing shaft furnaces in which dewatered material is dried and partially sintered.[141] The sinter can be crushed, mixed with portland cement, and used as a building material.[106, 294] The manufacture of light concrete aggregate by the suction sintering process has been described.[538] Rubble, slag sand, boiler ash, coal dump heat, fly ash, and clay can be utilized in this manner.[296] Sintered coal refuse can also be reworked to fibers, yarn, or wool.[105] The industrial significance of the elements in coal ash have been described by Headlee.[181]

COBALT

Wastes of cobalt xanthate containing cobalt, copper, and zinc have been sintered to recover these metals.[266]

See also: Lead; Pyrite Cinders and Tailings; Zinc; Reference 61.

COFFEE

Coffee grounds have been extracted to obtain oils, fats, waxes, and resins.[33]

COKE-OVEN GAS

See: Pickle Liquor.

COPPER

See also: Recovery and Utilization; Cobalt; Inorganic Residues; Lead; Pyrite Cinders and Tailings; Zinc; References 32, 66, 426.

BLAST FURNACES

The blast furnace has been used for melting copper scrap, the copper afterwards being refined in adjacent reverberatory furnaces.[509, 510]

CHEMICAL REDUCTION

Slags from copper smelters have been reprocessed into building materials by blowing air and carbon dioxide through the slag in the electric furnace and feeding lime and a solid reducing agent onto the surface of the slag.[111]

HYDROMETALLURGICAL PROCESSING

A process for producing copper tubing from scrap copper by a three-step procedure is described in *Iron Age*.[552] The copper scrap is leached in ammonium carbonate with aeration. After purification, the solution is treated at 325 F with hydrogen in an autoclave to precipitate copper powder. The powder is filtered from the solution and dried in an inert atmosphere, after which it is screened to yield closely controlled particle sizes for extrusion into copper tubing.

Similar techniques for dissolution in ammonium salts have been employed to reclaim copper from copper-clad steel and items such as small motors and generators. The residual iron can then be consumed in iron or steel making.

MELTING

A process has been developed to produce steel from copper slag. The slag piles at Anaconda, Montana, and Clarkdale, Arizona, have amounted to 40 and 30 million tons, respectively. About 3 tons of slag are required to produce 1 ton of steel.[140] Three plants were being erected to recover iron from copper slag. It was also planned to recover copper from the slag.[440, 561]

PRECIPITATION

Copper has been recovered from copper-bearing waste solutions by precipitation on iron.[305]

REVERBERATORY FURNACES

Reverberatory furnaces are used for melting, refining, and alloying copper, brass, and bronze scrap metals. The intent in processing these types of scrap is to sort the types so that marketable copper or alloys of copper can be produced with a minimum of refining, a minimum loss of alloying metals, and a maximum utilization of alloying metals from scrap sources. Preparatory operations, such as magnetic separation, drying, and baling frequently are required prior to furnace treatments.

A charge of copper-bearing scrap is first melted and then stirred and sampled for chemical analysis. The chemical analysis dictates the refining steps, which normally consist of fluxing, oxidation, and slagging. Suitable mixtures of limestone, silica, and iron oxides are added as fluxes to combine with oxides of metals so that those oxides may be removed from the furnace. In fact, oxidation of contaminating metals is induced by blowing air through iron pipes into the melt. It is frequently necessary to sample and analyze the metal again after the fluxing and refining operations. And finally, if the product is brass or bronze, additions of zinc, tin, or other alloying metals may be made to bring the product to specifications.

The slag from an operation of this kind is skimmed into pots and allowed to solidify. The slag generally contains enough copper to warrant reworking. This might be done by smelting it in a blast furnace. Alternatively, the slag from a reverberatory furnace might be crushed to liberate shots of metal from the mass of earthy material. The shots may be recovered by screening or by other physical methods. The final residual slag may or may not contain sufficient copper or other metal compounds to justify smelting to reduce those compounds to metals incident to their recovery.

SMELTING

Some copper and copper-base scrap has been smelted in primary smelters for the purpose of reclaiming only the copper. With this type of smelting, most or all of the alloying metals such as zinc and tin, are wasted. On the contrary, the brass and bronze ingot makers who treat scrap materials have endeavored to retain all of the valuable alloying metals, as well as the copper, from the scrap because bronze scrap ordinarily is purchased on the basis of the copper and tin contents of the scrap.

Reclamation of all of the metals in copper-base alloys is an apparent advantage in favor of secondary smelters. That advantage can be realized best if the scrap materials are sorted into types that can be made directly into saleable grades of ingots. If the scrap material contains undesirable contaminants, expensive refining operations are required, or the contaminants must be diluted to tolerable limits by blending with purer alloys or metals. In cases in which the contaminants are large or difficult to remove, it might be most economical to treat the scrap in a primary smelter, where copper can be traced from large proportions of iron, sulfur, and many other metals or compounds.

A means for reclaiming metals from starters and generators from obsolete automobiles is to charge the parts to steel-making furnaces to obtain copper-bearing steel. Starters and generators have also been treated in copper smelters to remove the iron as slag while the copper is collected as molten metal.

COTTON

Citric and malic acids are extracted from cotton-production wastes.[245]

See also: Reference 73.

DAIRY WASTES

See: Food-Processing Wastes.

DIAMOND GRINDING WHEEL DUST

Many grinding wastes contain fine industrial diamonds used in grinding operations. Although diamonds can be recovered by several methods, including acid leaching, separation in heavy liquids, and flotation, the procedures which have been used are proprietary and closely guarded.

The collection of diamond grinding-wheel dust from the tool-grinding operations of the Tungsten Carbide Tool, Incorporated, of Detroit, Michigan, has been briefly described in *Steel.*[514] Diamond dust has been collected at this plant in compact, filterless centrifugal collectors that weigh only 65 pounds each. These units were mounted on the walls of the plant, but they can also be installed on machinery, suspended from the ceiling, or placed on tables that occupy little more than 2 square feet of floor space. Each unit is priced under $200—no more than the cost of the average diamond grinding wheel. Almost one-fifth of the cost of a grinding wheel can be saved by the recovery of diamonds from the grinding dust.

DISTILLING WASTES

See: Brewing, Distilling, Fermenting Wastes; Molasses.

ELECTROPLATING RESIDUES

Metals are recoverable from some electroplating residues, but recovery processes have rarely been applied unless the waste contained precious metals. Metal sludge from the treatment of electroplating wastes has been combined with a variety of combustible wastes (fly ash, coal dust, paint sludge, oil, and grease) and burned in an incinerator on conical inclined, rotating grate containing perforations for the passage of ashes and clinker.[340, 388]

FERMENTING WASTES

See: Brewing, Distilling, Fermenting Wastes.

FISH

Gelatin is prepared from fish wastes.[38] Fish wastes are hydrolyzed and the product is used in the manufacture of cosmetic ointments.[428] Prawn-shell wastes have been extracted with acetone, decalcified, and refluxed with caustic to produce chitin.[234]

See also: Animal-Product Residues.

FLUE DUST

See: Ash, Cinders, Flue Dust, Fly Ash.

FLUORINE

See: Reference 123.

FLY ASH

See: Ash, Cinders, Flue Dust, Fly Ash.

FOOD-PROCESSING WASTES

The annual production of agricultural residues in the United States is something like three times the country's annual consumption of food. Agriculture residues are generated in large amounts throughout the world (e.g., the quantity of only one waste—bagasse—produced in the world each year amounts to about 300 million tons). Many of these wastes can be utilized as raw materials for production of chemicals and plastics, as cattle feed and mulch, and for manufacture of paper, board, and rayon. The Bureau of Agriculture and Industrial Chemistry of the Department of Agriculture has been investigating methods for utilizing these residues since 1935. A major deterrent to the construction of processing plants is the fact that much of this industry is seasonal. Installations designed on the basis of peak loads would remain idle much of the year.

See also: Animal-Product Residues; Bagasse, Fruit Wastes; Rice; Vegetable Wastes; Sanitary Landfill and Open Dumping; References 112, 292.

CARBONIZATION

Many carbonaceous waste materials have been used for the manufacture of activated carbon. The properties of the finished product depend on the waste carbonized. Decolorizing activated carbons have usually been employed as powders. Sawdust and lignin produce carbons of this kind. Vapor adsorbent carbons are usually in the form of hard granules and are generally produced from coconut shells and fruit pits (e.g., plum and apricot kernels). Carbonization proceeds at temperatures that are high enough to remove most of the volatile constituents but not high enough to crack the evolved gases.[413] Use of chemical impregnating agents causes carbonization to proceed under conditions that prevent the deposition of hydrocarbons on the carbon surface.[413]

Carbonization of residues from alcohol, beer, and sugar factories and of acorn husks is carried out to obtain activated carbon.[9] Sawdusts from various woods and peanut, cottonseed, and rice hulls are impregnated with $ZnCl_2$ or CaO and carbonized. The product is used for bleaching cottonseed oil.[244]

DEHYDRATION, DEWATERING, DRYING

Charcoal of high discoloration power can be obtained from various wastes (cottonseed and sunflower-seed hulls, corn husks, straw, sawdust, and lignite) by dehydration with sulfuric acid.[73] Pear, apple, potato, beet, whey, and other food-processing wastes have been dried and used for stock feed.[58, 425, 494] The high water content has restricted the use of food-processing wastes for many uses. Improved dehydration techniques are needed. Industries most likely to be customers for dehydrated food wastes that can be transported at low cost are the animal feed, chemical, and fertilizer industries.[59, 64]

DISTILLATION

Furfural has been obtained from various food processing residues by distillation with hydrochloric acid. Methods of improving the yield have been described.[496]

HYDROLYSIS

The cellulose in plant residues is readily saccharified and fermented. Sugars obtained in this manner have been used as feed to fermentation plants producing ethanol, methanol, acetone, butanol, and fusel oil, as well as protein, and yeast for cattle feed. The residue is a reasonably pure lignosulfonic acid solution. However, starch has generally been a cheaper raw material for glucose than cellulose.

OXIDATION

The Zimmerman process, which involves wet oxidation of wastes under pressure with partial recovery of fuel value, is applicable to some food-processing wastes.[64]

FOUNDRY WASTES

Foundry wastes have often been treated for the recovery of materials that can be recycled to the foundry operation. Foundry sand, metals, and alloys have commonly been recovered from various types of foundry wastes by means of magnetic separation, screening, gravity separation, and air classification. Recovered metals and alloys not recycled within the foundry can be sold as scrap.

St. John has described the general application of magnetic separation, screening, and gravity separation to the recovery of brass, foundry moulding sand, and metals from those wastes commonly generated in brass foundries.[500] These wastes include brass turnings, wet foundry sand, and metal-bearing nonmetallic material such as skimmings, skulls, slags, ashes, and refractories. Brass is usually recovered with a centrifuge and a magnetic pulley. It is usually recycled to the foundry, while tramp iron is sold as scrap. Vibrating screens are frequently employed for the recovery of molding sand from metal-sand mixtures. The cleaned sand is reused on the foundry molding floor, while the separated metallic pieces and core butts are subsequently treated for the recovery of the various metals they contain. Metals and alloys are often recovered from these and the nonmetallic waste materials by means of screens, shaking tables, ball mills, jaw crushers, and magnetic pulleys. The metal concentrate produced from the beneficiation of these wastes is either recycled to the foundry for melting or shipped to a secondary smelter.

The recovery of clean foundry sand from waste-containing, burned clay, carbonaceous material, and silica flour by means of magnetic separation, screening, and air classification has been described by Zimnawoda.[508] After the waste molding sand has been prepared by magnetic separation and screening, it is pneumatically scrubbed against the cone-shaped target of a dry pneumatic scrubber. Coatings of dehydrated clay and burned carbon are removed from the sand grains by attrition and separated from them by means of air entrainment and subsequent dust collection.

The application of this same dry pneumatic scrubber to the reclamation of foundry sand at the Superior Foundry, Incorporated, of Cleveland, Ohio, has been described by Barczak.[34]

Puryear and Wile have mentioned the use of magnetic separation and screening in their description of a thermal process employed by the Lynchburg Foundry Company of Lynchburg, Virginia, for the recovery of molding sand from waste containing a resin binder and a carbon residue.[380]

Herrmann has described the application of magnetic separation and screening to the preparation of a similar waste prior to the reclamation of sand by another thermal process employed at the Dearborn, Michigan, specialty foundry of the Ford Motor Company.[187]

See also: Inorganic Residues; Separation; Recovery and Utilization; Slag; Specific metals.

FRUIT WASTES

See also: Food-Processing Wastes; References 58, 437.

AMMONIATION

Dried, limed citrus pulp when ammoniated and treated with acid can be used as food for ruminants and fertilizer for plants.[65]

CHLORINATION

Chlorination of the terpene fraction of orange oil from orange peel produces a material useful as an insecticide.[132]

DISTILLATION

Products of the distillation of apricot kernels are benzaldehyde, benzoic acid, and hydrogen cyanide. The residue is fed to animals.[150]

EXTRACTION

Various by-products such as pectin, seed oils, limonene, peel oils, glycosides and vitamin P (citrin) are extracted from citrus wastes.[137, 424] Pectin and malic acid are extracted from apple wastes. A plasticizer has been made from the refuse from production of Chinese citron.[19]

GELLING

A process for producing dried pulp for cattle feed from peelings, cores, and trimmings wasted in canning of pears involves treatment of the waste to form a calcium pectate gel. The sediment from this treatment is pressed and dried and sold as cattle feed.[162, 330]

HYDROLYSIS

Pectin is produced by hydrolysis of dried peel of citrus fruits.[28] The products of hydrolyzing the protein in apple seeds have been described.[409] Grape wastes can be hydrolyzed to recover sugars and other chemicals.[97]

PYROLYSIS

Peach pits are charred and made into charcoal briquets.[292]

FURNITURE

See: Sanitary Landfill and Open Dumping; References 35, 530, 555.

GERMANIUM

An automated process for reclaiming high-grade germanium from scrap has been described.[532] Germanium chloride has been isolated by hydrolysis from wastes from the manufacture of diodes and transistors.[216]

See also: Lead; Nonferrous Scrap; Zinc.

GLASS

The Bassichis Company in Cleveland has since 1900 been processing and marketing powdered glass in various mesh sizes and types and is the largest in its field. Conventional processing machinery, adapted to this particular material and need has been used. Sources of scrap glass for processing have been altered drastically by many factors including two major trends, one technologic, the other economic: (a) the trend from bottles to cans and paper cartons, (b) the elimination by higher labor costs of the practice of salvaging broken glass from general refuse. As a result, some industries that could use cracked bottles as a raw material have had to turn to other materials because the supply of scrap bottles is too small and undependable. Thus, an economic method for segregating scrap bottles from municipal refuse would find a ready market. Dark glasses have been manufactured from industrial polishing waste and construction glass.[490]

See also: Recovery and Utilization; Reference 148.

EXTRACTION

Rare-earth elements in wastes from grinding optical glasses can be almost completely extracted by complex chemical procedures for experimental use.[11]

MELTING

Most glass manufacturers remelt for reuse the scrap glass resulting from their own processes if the scrap has not become contaminated with other materials along the way.

GLASS WOOL

See: Sanitary Landfill and Open Dumping; Reference 439.

GYPSUM

See also: References 189, 190, 209, 356.

CRYSTALLIZATION

When powdered waste gypsum from the pottery industry is heated with aluminum sulfate solution, large crystals of gypsum are obtained. The properties of the calcined crystals have been given.[173]

DEHYDRATION

Gypsum plaster has been manufactured from waste-gypsum molds by autoclaving.

HEMP

See: Reference 14.

HYDROGEN FLUORIDE

Slag from the manufacture of hydrogen fluoride has been washed, elutriated, crushed, and stirred with sulfates or chlorides to form pure crystals of calcium sulfate.[209]

INORGANIC RESIDUES

See also: Ash, Cinders, Flue Dust, Fly Ash; Foundry Wastes; Pickle Liquor; Slag; Specific inorganic residues; Reference 403.

In the mining and mineral industries, recovery of materials is rarely feasible.

All pyrometallurgical processes produce slags. Blast-furnace slag is produced in greatest quantity. The amount of slag is about equal to the amount of pig iron produced. All slags contain a certain proportion of the metal produced or refined, but recovery is not practiced to any extent. There are several mechanical uses for slags. They are used as aggregates, rail ballast, housing-project foundations, and gravel for roadmaking and railway building, and in practically all circumstances where gravel or crushed stone could be used. A serious drawback to many slags is their tendency to dust or disintegrate during the course of time. Chemical uses of slags include their use as cement, fertilizer, and slag wool.

Three kinds of sludge are produced in the steel industry: flue dust, mill scale, and neutralized pickle liquor. About 1 billion gallons of pickle liquor are generated in the United States each year. This amount of pickle liquor contains 250,000 tons of iron. The total amount of solids in spent, neutralized pickle liquor amounts to about 2 million tons each year. The neutralized slurry remains plastic for an almost infinite time. Pickle liquor can be processed for recovery of iron and iron compounds and acid. These processes are becoming more widespread as time goes on. The neutralized sludge can be used as a construction material. Flue-dust sludge is generally filtered, sintered, and returned to the blast furnace. The average furnace produces about 1,000 tons of dust a day. The scale removed in rolling mills is deposited in a scale pit and is usually charged to the furnace. It amounts to about 60 tons per day for a rolling operation.

IRON

See: Copper; Foundry Wastes; Inorganic Residues, Pickle Liquor; Pyrite Cinders and Tailings.

LEAD

See also: Tetraethyllead; Waste Recovery and Utilization.

Lead scrap can be made into the various grades of pure lead or into lead alloys by secondary smelters. This is possible because the usual impurities in lead scrap can be removed readily. Hence, lead battery plates may be smelted to produce antimonical lead for the manufacture of new batteries, or the lead may be refined to produce pure lead and pure antimony as separate products. In either case, the antimony as well as the lead is returned to industry. This is important because both the antimony and the lead content generally are paid for in purchasing scrap battery lead.

CHEMICAL REDUCTION

Lead waste from electrodes of storage batteries containing lead sulfide has been molded with carbide sludge and water and chemically reduced.[492]

MELTING

Lead has also been reclaimed from various solid wastes by melting.[122, 136]

REVERBERATORY FURNACES

Lead is recovered from a variety of materials by use of reverberatory furnaces. Battery plates, which constitute the largest source of scrap lead, usually are smelted in blast furnaces to produce antimonial lead. That product may be made into soft lead (free from antimony) in a reverberatory furnace or in a kettle. Battery plates also are melted in a reverberatory furnaces directly to produce antimonial lead. A variety of lead alloys from scrap pipe, coffins, bearings, and roofing also are melted in kettles or reverberatory furnaces. The lead from most of its scrap materials can be refined to products equal to the refined lead from primary smelters. In fact, the refining steps, softening (removing antimony), decopperizing, dezincing, and debismuthizing may be the same in secondary plants as in primary smelters.

Reverberatory furnaces also are employed to smelt various lead drosses, especially those obtained from the refining of scrap lead in kettles. And reverberatory furnaces in turn produce slags and drosses that are smelted best in blast furnaces. A rather complex relationship exists between the melting, smelting, and refining of the many types of lead scrap and the equipement used for the operations.

LEATHER FABRICATING AND TANNERY WASTES

Leather wastes have been processed to manufacture glue, carburizing agents, and fertilizer. Tannery wastes have been used to produce feed. Fertilizers have been produce from waste leather.[421]

DISSOLUTION

Constituents of glue have been recovered from leather wastes by various dissolution processes.[41, 74, 392]

HYDROLYSIS

Collagen-containing wastes of the leather industry have been treated by hydrolysis to produce an artificial leather.[459] Albuminoid hydrolyzates prepared from leather wastes can be used in cosmetic preparations.[398] Protein-containing skin, bones, and other tannery refuse can be hydrolyzed to produce a food product.

PRECIPITATION

Chromates can be recovered from tanning wastes by precipitation.[373]

PYROLYSIS

Waste leather or wool can be autoclaved and the residue used as fertilizer.[421] Leather trimmings can be converted into a carburizing agent by heating in a muffle furnace and then mixing with calcium carbonate.[235]

LEAVES

See: Sanitary Landfill and Open Dumping; Reference 91.

LIME

Waste from lime works has been mixed with coal wastes, formed into shapes, combined with solid fuel, and burned to a clinker.[330] Various lime wastes are used in the liming of podzolic soils.[237] Some lime sludge is also dried and used for acid-waste neutration.

See also: Stone Spalls; Sugar Beets; References 57, 234.

MAGNESIUM

Hydrochloric acid has been used to leach iron and aluminum from the solid wastes from magnesium production.[131]

See also: Aluminum.

MANGANESE

Metallic manganese has been obtained by electrolysis of a solution of manganese obtained by extracting a mixture of manganese containing slags and pyrolusite.

MICA

Mica has been recovered in sheets after chemical processing of wastes from mica mines.

MINERAL WOOL

See: References 105, 346.

MOLASSES

Potassium salts have been recovered by incineration of wastes from molasses.[43]

See also: Brewing, Distilling, Fermenting Wastes.

MOLYBDENUM

See: Reference 145.

MUNICIPAL WASTES

Only one chemical method, incineration, has been practiced for the disposal of municipal wastes. It employs oxidation of the waste with free air at elevated temperatures. A variant of this process, so-called "wet oxidation," has been practiced to a limited extent in recent years, with at least one application to sewage sludge.[501] In the process, the sludge is oxidized to destruction by pumping a water suspension of it and air into a pressure vessel; both are maintained for some time at elevated pressure and temperature.

See also: Incineration; Reference 163.

NONFERROUS SCRAP

Precious metals are recovered from a great variety of industrial waste materials. Examples of annual recoveries of nonferrous metals during 1964 are: over one-half million tons of aluminum, slightly more than one million tons of copper, and 120,000 ounces of platinum-group metals. The less common metals, such as germanium, zirconium, and yttrium are also reclaimed from scrap metals.

The term "secondary", when used in connection with metals, does not refer to quality. It refers to metals produced from scrap or waste materials to distinguish them from "primary" metals, which are produced from ores and concentrates of ores. Two other designations are used in the secondary-metal industry; namely, "new scrap" and "old scrap". The scrap generated as turnings, punchings, trimmings, damaged parts, and the like, by fabricators of machinery and equipment is called new scrap. Metals salvaged from obsolete machinery, buildings, or ships is termed old scrap.

Most manufacturers prefer to send their scrap metals to plants established for the processing of such materials. Consequently, the source of much of the secondary metals is manufacturing plants. The other sources are the scrap metals brought to dealers by collectors from small shops, municipal refuse, obsolete machinery, and dismantled buildings.

A great deal of sorting and processing of scrap materials may be required preparatory to the production of marketable metals. The smelting and refining of metals is much simpler and less expensive if relatively pure types of metals are treated separately. This makes careful sorting advantageous. Various operations, including sorting, drying, degreasing, incinerating, and baling, are used in the preparation of scrap metals for smelting and refining.

The actual production of marketable metals from scrap materials involves five major processes: melting, melting and refining, smelting and refining, distillation, and hydrometallurgical processes.

Ample facilities and processes exist for producing useful metals from metallic scrap. This makes it possible for small amounts of scrap from scattered sources to be brought to strategically located centers. The scrap can be processed economically at those centers because the volume of material can be sufficiently large for the purpose.

See also: Recovery and Utilization; Foundry Wastes; Inorganic Residues; Precious Metals; Pyrite Cinders and Tailings; Specific nonferrous metals; Reference 148.

NUTS

Extraction of cashew-kernel rejections gives a bland yellow oil. The residue can be used in the manufacture of chocolate or as feed.[402]

Destructive distillation of the hulls of groundnuts yields gas, acetic acid, methanol, and charcoal.[463]

See alsc: Agricultural Wastes; Food-Processing Wastes; Reference 463.

NYLON

Nylon fibers can be recovered from waste nylon by destroying the non-nylon portion of the waste with acid.[333] Waste nylon has good ion-exchange properties.[26] Chemical treatment of Nylon-6 waste has been reviewed by Diba and Varacek.[109] Nylon-6 wastes have been depolymerized to 6-caprolactam by alkaline depolymerization at elevated temperatures or by hydrolysis.[109] Nylon-6 waste can be dissolved under pressure in alcohol, particularly ethyl alcohol; the polymer will precipitate in the form of fine particles when the solution is cooled.[109] It can be dried and reused. Polyamide (nylon) wastes can be dissolved and reprecipitated; the precipitate can be reused to produce nylon.[217, 351] Waste nylon-6 can be treated with an alkaline solution to precipitate impurities. After the rubbery precipitate is filtered off, caprolactam can be isolated from the solution.[352]

See also: Agricultural Wastes; Plastic; References 304, 307, 371, 414.

ORGANIC WASTES

Many organic industrial waste sludges can be burned with little or no auxiliary fuel after they have been partially dewatered by filtration, centrifugation, or screening. By use of multiple hearth incinceration (where heat economy is relatively high) even liquid sludges can be burned. An apparatus for purifying industrial effluents and utilizing organic matter for fuel is described.[500] Carbonaceous waste materials can be destructively distilled in a retort. Condensible materials are removed from the vapor, and the remainder is returned to the retort. The solid can be used for charcoal.[283] The simultaneous carbonization and sulfonation of organic wastes produces a granular carbon possessing ion-exchange properties.[398]

See also: Agricultural Wastes; Animal-Product Residues; Food-Processing Wastes; Fruit Wastes; Vegetable Wastes; Specific organic wastes; References 395, 396.

PAINT

The solid material demanding ultimate disposal by paint users is the paint-waste sludge removed from holding pits in spray booths. This waste is in the form of a sticky mass with the consistency of modelling clay.

INCINERATION

Paint sludge has been burned in pit incinerators.[29, 358] Air pollution from these installations may be a problem if the solids content of the sludge is high.

POLYMERIZATION

A method which has been considered for disposal of paint waste is polymerization by heating to a temperature and for a time equivalent to practice in curing paint.[29]

PAPER

See: Photographic Paper; Pulp and Paper; Wastepaper.

PETROLEUM RESIDUES

Petroleum residues include tank bottom sludges from storage tanks and cracking, polymerization, and similar processes; coke from equipment tubes and towers; oil emulsions and oily waste waters from cracking and distillation and similar processes; and acid sludges, caustic sludges, and emulsions from the chemical treatment of oil. Petroleum residues are usually disposed of by incineration after removal of most of the oil and water from these residues.

CARBONIZATION

Activated carbon has been produced by burning the sludges from oil refineries.[40]

DISTILLATION

Distillation of petroleum residues yields a material that is a plasticizer and agglutinant.[303]

INCINERATION

Petroleum sludges are usually disposed of by incineration after as much of the oil is recovered as possible. These sludges may be viscous liquids or semisolids containing water, free acid or alkali, and other chemicals. The calorific value on a dry basis is 10,000 to 15,000 Btu per pound. Efficient heat recovery is not possible without carefully designed equipment.[177] Thermal disposal methods are recommended for disposal of sludge from leaded-gasoline tanks.[30]

The coke residue from petroleum refining has generally been burned with coal for heat recovery, but it can be burned alone in a specially designed furnace. The sulfur content may introduce corrosion or sulfur dioxide problems. The high vanadium content of the ash can also cause corrosion.[177] The economics of using this coke as fuel have been reported.[306]

The oily sludges from treatment of waste emulsions have been incinerated by flame incinerators and fluidized-bed techniques.[29]

PHOTOGRAPHIC PAPER

Silver and gelatin-free paper can be recovered when photographic paper wastes are treated with calcium oxide and alum in a beater.[291] Silver can also be recovered from photographic wastes by burning the wastes under controlled conditions and recovering the silver from the ash by smelting.[130, 380, 481]

See also: Chemical Wastes; Plastic; References 293, 362.

PICKLE LIQUOR

See also: Inorganic Residues.

CALCINATION

The ferrous sulfate by-product of pickle-liquor regenerative processes can be roasted to produce sulfur dioxide suitable for sulfuric acid.[186]

CRYSTALLIZATION

Waste pickle liquor has been regenerated using high-acid (18%) baths. The spent bath is evaporated, seeded, and acidified and the ferrous sulfate removed by crystallization. The acid supernatant can be reused.[290]

DISPLACEMENT

In the Ruthner process, sulfuric acid and iron oxide are recovered from spent pickling liquor by converting ferrous sulfate to ferrous chloride and sulfuric acid by reacting it with hydrochloric acid. The ferrous chloride precipitate is roasted to reclaim hydrochloric acid, and the ferrous oxide is returned to the blast furnace. A demonstration recovery plant based on this process was operated at the Niles, Ohio, plant of Republic Steel Corporation. Seven major steel companies shared the cost of the $400,000 program.[277, 534]

ELECTROLYSIS AND ELECTRODIALYSIS

Iron and sulfuric acid can be recovered from pickle liquor by electrolysis.[132, 290] Iron is deposited on the cathode and sulfuric acid is recovered in the anode solution by electrodialysis of spent pickling solutions. The capital cost of a plant treating 1,720 gallons per hour of pickle liquor (10 TPD iron) was reported as about $2.5 million. Operating cost was reported as $3.070 per day, and credits came to $1,593 per day.[277]

EVAPORATION

Ferrous sulfate can be recovered from pickle liquor by evaporation.[290] Sodium sulfate can also be recovered by evaporation.[515]

EXTRACTION

Iron in spent pickle liquor can be complexed and extracted. The iron is recovered by adding lime to the extract. Acid can also be reclaimed in the process.[553]

NEUTRALIZATION

Metallurgical sludge containing calcium oxide and magnesium oxide can be used to neutralize spent pickle liquor.[323]

SCRUBBING

Iron oxide and ammonium sulfate are produced when coke-oven gas is scrubbed with spent pickle liquor.[373]

PLASTIC

Many waste plastics can be processed for reuse. Most thermosetting plastics, however, defeat attempts at large-scale utilization and are not even suitable as fuel because the decomposition (ignition) temperature is high and the flame is not self-sustaining. One or two varieties have been used as fertilizer and some, when ground fine, may be useful as filters. Preliminary experiments have been made to obtain usable materials from bakelite scrap by means of acetylation, methylation, halogenation, sulfation, or nitration.[306]

See also: Recovery and Utilization; Agricultural Wastes; Nylon; References 148, 331.

ALCOHOLYSIS

Lacquer resins can be prepared from the waste products of polyethylene terephthalate by their alcoholysis with glycerol.[404] Cellulose film wastes can be treated by transesterification. The products can be used in the preparation of thermoplastic materials.[362]

CONDENSATION

Waste polyethylene glycol has been heated with ethylene glycol and the mixture polycondensed. The product can be molded.[108] Spinnable polyethylene terephthalate can be obtained from fiber waste by a condensation process.[403]

DISSOLUTION

Cellulose-ester film scrap has been treated with caustic and ferrous sulfate, dissolved in dichloromethane and methanol, and centrifuged to produce a clear solution that can be reused.[94] Waste synthetic polymers which have been recovered by dissolution processes include acrylic, vinyl, and polyester resins.[62]

DISTILLATION

Polymethacrylic resin waste products can be chemically treated and distilled to recover methyl methacrylate.[31]

EXTRACTION

Polyurethane scrap can be extracted with an alkaline solvent to remove a portion of the waste polyurethane, which, after chemical processing, can be reused.[86] Several waste synthetic polymers can be dissolved without apparent chemical change and then reused after the solvent and impurities are distilled off.[62, 414] Caprolactam can be recovered from superpolyamide wastes by heating, dissolving, treating with activated carbon, and filtering.[363] Several solvents can be used in the recovery of polymer from waste nylon-6, including 6-caprolactam: sulfuric acid, hydrochloric acid, formic acid, calcium chloride and methyl alcohol, water under pressure, and alcohols under pressure. After extraction, the polymer is recovered by precipitation.[371] Extraction of organic components to regenerate asbestos from plastic products was not successful.[284]

HYDROLYSIS

Polyethylene terephthalate waste has been subjected to complete alkaline destruction, aqueous hydrolysis, and methanolysis before reuse.[438] Waste nylon has been hydrolyzed to recover raw materials.[304, 307] Polyester urethane can be treated by hydrolysis with steam and the recovered material blended with new material.[348] Cellulose acetate wastes or cellulose 2,5-diacetate obtained by hydrolysis of photographic film can be treated with epoxy resins, the resultant mixture being crushed, ground, and granulated before reuse.[117] Recovery of the polymer in waste Nylon-6 can be accomplished by hydrolysis.[109] Synthetic resins that contaminate wastepapers can be removed by hydrolysis.[236]

INCINERATION

For a very large number of chemical and plastic wastes the degree of burnability, decomposability, corrosiveness, and hazard is unknown.[380] The liquid residue from burning scrap polyurethane can be returned to the normal foaming process without decreasing the quality of the final product.[143, 380] Rigid polyurethane-foam particles have been heated to give rigid products useful in place of wood panels and tile.[15] Polyesters have been recovered from scrap polyurethane by burning in air.[12] The pit incinerator has been used to incinerate nylon wastes.[29] Excess activated sludge from treatment of nylon-plant wastes has been mixed with equal parts of combustible waste and incinerated.[365] Asbestos in waste plastics has been regenerated by burning away the organic matter.[284]

MELTING

Polyethylene terephthalate in waste fibers has been melted, and the melt condensed and extracted to recover spinnable polyethylene terephthalate.[404] Polymer of nylon-6 waste has recovered by melting.[371]

POLYMERIZATION

Methods for processing plastic wastes for repolymerization have been described by Tobola.[451] Polyamide wastes have been mixed with monomers and autoclaved to produce a copolymer.[412]

PYROLYSIS

Synthetic resins can be cracked *in vacuo* by direct contact with melted metals.[373]

POPPY

Morpnine is extracted from poppy wastes.[207]

POTTERY WASTES

See: Gypsum.

PRECIOUS METALS

Scrap that contains precious metals may be worth processing. A checklist of precious-metal scrap has been presented by Perry.[340]

Gold, silver, and the platinum-group metals have been reclaimed from a great variety of industrial waste materials. Combinations of melting and chemical treatments have been applied to separate and to refine the metals. Dissolution and precipitation have been practiced to separate the previous metals from base metals or from catalyst carriers and to concentrate the precious metals into small bulk. The great value of the metals permits the use of very corrosive reagents because small units of expensive equipment can be employed. Glass-lined vessels, glass pipelines, and glandless pumps have been used extensively. Earthenware, rubber-lined steel, and stainless steel have also been used for digestors, filter presses, and cementation vessels. Some typical methods are decribed briefly in the following paragraph.

Nitric acid or sulfuric acid can be used to "part", that is, to selectively dissolve, silver from gold in alloys that are preponderantly silver. The silver can be recovered from solution by cementation with copper. Finally, the separated gold and silver can be refined by electrolysis or other means and cast into bars for delivery.

In the treatment of the platinum group of metals, solutions containing the major portion of the gold, platinum, and palladium as chlorides can be prepared by digestion with aqua regia. This treatment leaves a residue of the less soluble metals, iridium, rhodium, ruthenium, and osmium. Gold can be recovered from the solution by reduction with ferrous chloride and filtration. Ammonium chloride can be added to the filtrate to precipitate ammonium chloroplatinate. The precipitate can be filtered and calcined to produce platinum sponge. Palladium can be precipitated as dichlorodiamminepalladium; palladium sponge can be obtained by calcination of the filtered precipitate.

The original residue of iridium, rhodium, ruthenium, and osmium can be fused with alkaline and oxidizing fluxes. The fused mass can be dissolved in water and distilled to separate ruthenium and osmium as volatile oxides. These metals can be precipitated as complex salts in the manner described for platinum and the precipitates calcined to metallic sponges. The residue from the distillation would contain iridium and rhodium. It can be treated to precipitate complex ammonium compounds separately, and those precipitates can also be calcined to yield metallic sponges of the iridium and rhodium.

The separate sponge metals can be converted to solid ingots or other suitable shapes by melting and casting or by sintering, forging, and rolling.

See also: Recovery and Utilization; Ash, Cinders, Flue Dust, Ash Fly; Electroplating Residues; Nonferrous Scrap; Photographic Paper; Specific metals; References 389, 391.

PULP AND PAPER

The solid wastes generated by pulp and paper mills are mostly in the form of sludges. The amount of solids discharged from a mill varies from about 20 to 160 pounds of solids per ton of paper produced. About 70 million tons of pulp are produced in the world per year. Waste solids from this industry amount to something like 3.5 million tons per year. The solids content of the sludges may be as low as 0.75 percent or as high as 10 percent. The sludges from pulp-mill effluents are composed primarily of cellulose and inert filler materials. They also can contain starch, rosin, casein, inks, and other organics together with grit, wood, wire, rags, and other miscellaneous trash. The sludge from a white-water recovery system is almost entirely cellulose fibers.

Final disposal of sludge has usually been on the land. It has generally been disposed of in the liquid state, but more and more plants are using some form of dewatering equipment so it can be handled in the semisolid form. Sludge-burning methods such as the Zimmerman and Atomized Suspension techniques have seemed to be promising methods for further decreasing the sludge volume.

A number of paper companies in the United States have concentrated sulfite waste liquor to 50 percent solids and sold it as such or as a powder produced by spray drying. The product modified for particular applications can be sold as a binder or a dispersing agent. A small amount has been sold in the form of metal complexes for agricultural applications.

Chemicals have been recovered from the sludges at some plants. The Ontario Paper Company has processed sludge for recovery of 4,800 pounds per day of vanillin, 2,400 pounds per day of calcium oxalate, 2,400 pounds per day of lignin, and 120,000 pounds per day of sodium sulfate.

See also: Recovery and Utilization; Wastepaper; References 68, 148.

CALCINATION

A fluidized-bed reactor can be used to calcine lime mud from recaustizing operations at paper mills. The lime can be reused. The reactor capacity of a mill using this process was reported as 45 TPD.[196, 209] Calcined deinking mill sludge can be used for filler and in the manufacture of building materials.[324]

COMBINATION AND ADDITION

Dimethyl sulfide can be produced from kraft liquor. The process consists of adding sulfur to the liquor, heating, and flashing off crude dimethyl sulfide, which is then condensed and purified by extraction and distillation. About 60 pounds of dimethyl sulfide have been produced per ton of kraft pulp. A smaller amount of methyl mercaptan can be produced and isolated. Several plants have been in operation. One produced 5 million pounds per year of dimethyl sulfide.[182, 376, 586] Pressure heating kraft liquor with additional sodium sulfide and sodium hydroxide yields ether-soluble degradation products (up to 50 percent or more of the organic substances) plus methyl sulfide, acetic and formic acids, and a reactive demethylated lignin (yielding pyrocatechol and its homologues, usable in plastics of the bakelite type).[130] The cellulose in paper wastes reacts with methanolic hydrogen chloride to produce methyl glucoside, which can be used to make polyethers for urethane foam. Starch can be used as a raw material for polyethers.[152]

DEWATERING

The problems of dewatering paper-mill sludges have been described.[152, 251, 474]

DISSOLUTION

Wastepaper ingredients (e.g., ink) are dissolved by cooking the paper in a mixture of chemicals, principally caustic soda; the fiber residue is suitable for reuse.[325]

DISTILLATION

Tall oil from black liquor can be redistilled and sold as such or sent to a fractionation operation where rosin and fatty acids are recovered.[50] Methanol is recovered by distillation of evaporated black-liquor solids following treatment with barium hydroxide.[373] Pine oil is separated from sulfate turpentine by fractional distillation. Between 0.2 and 2 gallons of pine oil are produced per ton of pulp. The turpentine is recovered by decantation from the condensed relief gases from kraft digestion at the rate of 1 to 6 gal/ton of pulp.[373] Turpentine and rosin are distilled from pine gum and stumps.[182]

ELECTROLYSIS AND ELECTRODIALYSIS

Spent sulfite liquor is being treated on a pilot-plant scale by electrodialysis to recover pulping liquor, produce lignosulfonic acids, and separate lower molecular-weight organics. The plant is being operated by the Sulfite Pulp Manufacturers' Research League in Appleton, Wisconsin.[327]

By electrolyzing fibrous waste suspended in a sodium chloride solution, the fibrous material is simultaneously digested and bleached.[359]

EVAPORATION

Lignosulfonates are produced by evaporation of sulfite liquors to 50 percent solids in a self-descaling evaporator. It is an advantage to convert the calcium lignosulfonates to the soluble sodium form by ion exchange prior to evaporation.[373]

EXTRACTION

Acetic and formic acids have been recovered from the waste liquors from neutral sulfite semichemical pulping by an extraction process.[335, 475] Tannins have been extracted from the bark of trees including the two principal pulp trees in the Pacific Northwest, Douglas fir and western hemlock. In addition, hemlock bark has been extracted for phenolic acids. Arabogalactan has been extracted from western larch by the lumber division of one of the large paper companies. Several other complex wood extractives can be produced from wastes. The possible isolation of wax from Douglas fir bark has been investigated. Methods have been found for extracting xylose from hardwoods.[183] The sludge precipitated by treating an alcohol plant effluent with lime has been leached with soda ash. The calcium carbonate residue has been reused in the process. Vanillin, lignin, calcium, oxalate, and sodium sulfate have been recovered from the leaching solution. The raw material for an alcohol plant was the effluent from the pulp mill.[512]

Asphalt-coated paper, when treated with certain solvents, has been claimed upon solvent evaporation to contain the asphalt in microscopic particulate form, permitting its use as an ingredient in pulping operations.[16] Bitumen-containing wastepapers can be utilized in the papermaking process after extraction with acid.[397]

The ash from the incineration of spent cooking liquor from the kraft process can be leached and the extract causticized to recover caustic and sulfide chemicals used in the process.[171]

HYDROGENATION

Phenolic materials can be produced by hydrogenation of lignin in papermill wastes.[373] Sugars in sulfite-waste liquors can be hydrogenated to alcohols. There has, however, been no economical means of separating the sugars from the other waste solids.[183]

HYDROLYSIS

Many attempts have been made to profitably utilize the vast quantities of waste lignin from pulping processes and wood hydrolysis. Recovered lignin can be used in the preparation of synthetic resins.[425] The characteristics of lignin have been described.[338, 342, 373] The sugars produced by hydrolysis in the sulfite-pulping process are converted to alcohol and yeast.[182] A kraft mill with a capacity of more than 1,400 TPD uses shavings and sawdust to produce pulp.[542]

INCINERATION

The burning of papermill sludge (solids obtained from the so-called white water from paper machines) has been limited in the United States. The economics of the process is dependent on the moisture content and the Btu content of the sludge. The Btu content per pound of sludge volatiles is on the order of 8,000. The heat needed to volatilize a pound of water ranges from 1,900 to 3,500 Btu. Data on the degree of dewatering required of sludges of various volatile contents to support their own combustion has been presented in graph form by Blosser.[49]

The Zimmerman process, which employs the principle of wet combustion, has been used for combustion of paperbill sludges and liquid disposal.[39, 329, 502, 541] Wet-combustion economics are almost independent of the dry-solids content of the waste. This process is installed at the A/S Boregaard mill at Sarpborg, Norway. Installation costs for a unit to burn 200 tons per day of dry solids have been reported to be in excess of $11 million.[52]

The atomized-suspension technique was developed by the Pulp and Paper Research Institute of Canada for burning sludges. In this process, after some heating and thickening by exhaust gases, sludge is injected through nozzles or other atomizing devices into a heated chamber, where it is burned at atmospheric pressure.[49, 256, 263, 551]

Burned sludges have been used as filter material for rubber and asphalt tile.[49] Pelletized sludge subjected to high temperatures has been used as a lightweight concrete. It might also be used to manufacture lightweight brick.[49] A mixture of sugar-factory muds, papermill sludge, and clay yields portland cement when it is burned.[455]

Experimental incineration of papermill sludges has been described.[48, 529]

Black liquor from sulfate pulping has nearly always been evaporated and incinerated. The liquor is brought to 50 percent solids in multiple-effect evaporators and is further evaporated to 65 percent solids in direct-contact evaporators. This is then fed to the recovery furnace where the organics decompose, carbon is burned away, and the inorganics melt and are reduced. Caustic soda, sodium sulfide, and soda ash are recovered from the smelt.[373, 481]

Acid calcium sulfite liquor has often been evaporated and incinerated as an antipollution measure. Steam is produced as a by-product. Scaling is a particular problem in these evaporators. The capital investment for evaporation and incineration for a 200-TPD plant has been reported to be $1.5 million, with a negative return on investment.[373]

In the case of magnesium-based cooking liquors, the evaporated liquor is burned in a recovery furnace. Sulfur dioxide is then recovered by wet scrubbing, and magnesium oxide by dry scrubbing, for recycle. Both ammonium- and sodium-based liquors may be treated in this fashion. A recently proposed approach has been the use of atomized-suspension radiant pyrolysis for the incineration of sulfite liquors. The capital investment for evaporation and incineration for a 250-TPD plant has been reported as $5.2 million and rate of return as 16 percent.[373] Sulfur has been recovered from the gas during combustion and reused.[180, 483] A fluidized-bed system has been used to recover chemicals, such as sodium sulfite and soda ash, in the Container-Copeland process.[97]

ION EXCHANGE

The Pritchard-Fraxon and Abiperm processes are examples of ion-exchange recovery systems for sodium-, magnesium-, calcium-, or ammonium-based liquors.[373] The capital investments for ion-exchange systems for 100-, 200-, and 300-TPD plants have been reported as $767,000, $1,163,000, and $1,511,000, respectively. Rates of return have been reported at 9.0, 12.4, 14.7, in the same order.[373]

OXIDATION

Meso-tartaric acid can be obtained by oxidizing cellulose with nitrogen tetroxide and then hydrolyzing with hydrochloric acid.[182] Materials containing lignosulfonic acid can be oxidized in alkaline medium to obtain vanillin, acetovanillin, lignin, and calcium oxalate.[334]

PRECIPITATION

In the Howard process, various portions of the sulfite pulp wastes are separated by fractional precipitation. One portion is burned to provide heat, and the residue is processed to recover chemicals. Other fractions contain materials useful as raw materials for the manufacture of plastics and vanillin.[171] Lignin can be recovered from kraft liquor by precipitation of the lignin with acid. The lignin so obtained can be processed into useful chemicals.[182]

PYROLYSIS

Practically all vanillin has been produced by the alkaline pyrolysis of lignin sulfonic acid from sulfite-waste liquor. The yields are low, between 6.0 and 12.0 percent based on the lignin sulfonic acid, and an elaborate extraction and purification process is required to produce a pure product. In North America, about 1.5 million pounds of vanillin are produced per year and sold at about $3.00 per pound. Most of the vanillin has been used for flavoring, a small amount being converted to other flavoring agents and medicinal derivatives.[182, 442]

The cracking of lignin gives a source of chemical raw material comparable to coal-tar production.[182] Cellulose heated in a vacuum to relatively high temperatures produces 1,6-anhydroglucose, which can in turn be polymerized. Its trimethyl ether, when treated with sodium in liquid ammonia, produces phenol in yields that have been reported at over 50 percent.[183] Activated charcoal is produced by pyrolysis of black-liquor effluents.[182]

SMELTING

There are several processes for recovering heat and chemicals from sulfite wastes by evaporation followed by smelting. Among these are the Institute process, the Mead process, the Sivola process, the Stora Kopparberg process, the Western Precipitation (Bradley) process, the Sulfox process and the A. D. Little process. The capital investment for smelting for a 200-pound-per-day plant ranges from $2.45 million to $3.32 million, depending on the process used.[373]

PYRITE CINDERS AND TAILINGS

A number of nonferrous metals can be recovered from cinder, which is the residue, essentially iron oxide, from burning pyrite for the manufacture of sulfuric acid. Cinders, in some circumstances, are valuable as sources of iron for making iron and steel. In many cases, however, cinders contain small but objectionable amounts of nonferrous metals. Hence cinders can be processed to recover nonferrous metals while beneficiating the iron product. The kinds and amounts of recoverable nonferrous metals in cinder depend on the composition of the pyrite that is burned in forming the product. One author has stated that a mixture of residues from pyrite produced in European countries contained over 50 elements. Most of those elements were present in such minute amounts that recovery was not feasible.

Copper, cobalt, and zinc have been recovered from cinders containing less than 1 or 2 percent of any one of these elements. The usual procedure is to roast the cinder, mixed with about 10 percent of common salt, at about 1,100 F in multiple-hearth furnaces. The gas from the roasting furnaces is scrubbed with water, and the resultant liquor is used to leach the calcine produced. The roasting operation renders the desired metals soluable in the weak acid effluent from the gas scrubber.

Copper is removed from the leach liquor by cementation with scrap iron. The product is sent to a copper smelter for refining and marketing. If cadmium, thallium, and indium are present in the decopperized liquor, they are precipitated by comentation with zinc dust. Cobalt is removed by oxidizing with chlorine and precipitating with zinc hydroxide. The filtered precipitate is calcined to produce cobalt oxide for sales. Zinc is precipitated as zinc hydroxide by use of lime. The precipitate is thickened, filtered, dried, and finally calcined to produce material suitable for reduction by the electrolytic process.

Iron oxide can be recovered from pyrite tailing by heating the tailings to 2,000 F. The liquid ferrous sulfide can be granulated and roasted to give iron oxide and sulfur dioxide. Sublimed lead, zinc, and sulfur vapor can be condensed and separated.[535] Pyrite wastes can be purified by extraction and reused.[128]

See also: Coal Refuse.

REFRACTORY

The W. E. Plechaty Company of Cleveland has developed a nearly automated process for reclaiming refractory material from nearby steel mills. In steel manufacture, refractory linings in furnaces and ladles are eroded by the process so that at least 50 percent of the refractory is lost in the slag. When the remaining refractory is too thin for proper containment, the furnace or vessel is shut down, and the deteriorated refractory is removed and replaced by the new refractory. The discarded material is removed from the mill and is processed in the following manner: (1) magnetic removal of all irons; (2) screening of all fine particles either good or bad; (3) hand sorting to type and quality; and (4) crushing and screening for a marketable refractory product.

The high costs of automation, the industry's label of "salvage or used", and the lack of trained supervision in this field have combined to place a tremendous limitation on expansion of this reclaming system into other areas.

See also: Foundry Wastes; Reference 116.

REFRIGERATORS

See: Sanitary Landfill and Open Dumping; References 35, 530, 555.

RICE

The adsorption properties of carbonized rice hulls and rice stalks have been evaluated.[387]

See also: Food-Processing Wastes.

RUBBER

See also: Reference 303.

INCINERATION

Use of a two-combustion-chamber incinerator incorporating burners in both chambers to insure complete combustion reportedly solves the odor and smoke problem of incinerating rubber wastes.[328] A packaged unit complete with afterburner is marketed and used for incineration of rubber waste.[500]

OXIDATION

Ozonization treatment of rubber waste with hydrogen peroxide yields a material useful in polymerization.[170]

PYROLYSIS

Under proper conditions of pyrolysis, waste rubber yields materials that are useful as solvents, plasticizers, and surface-active agents. Thermal cracking of waste rubber yields a mixture of maleic acid and oil which is useful as a plasticizer.[129] Pyrolysis of waste rubber yields a fraction that can be used in the production of surface active agents.[358] Scrap rubber can be destructively distilled leaving an ash residue.[81, 418] Distillation of scrap rubber results in a light fraction suitable for a varnish solvent and a residue that can be used as a filler.[108]

SAL SKIMMINGS

Sal skimming are spent flux removed from the surface of galvanizing baths on which fluxes are used. They are a mixture of metallic zinc, zinc oxide, and some of the zinc ammonium chloride of the original flux. Sal skimmings are the least desirable and hence the least valuable of the wastes from galvanizing operations. They are poorly suited to the distillation and electrolytic processes for reclaiming zinc because of their chloride content. For that reason, most of the sal skimmings produced in the United States (over 25,000 tons annually) are treated chemically.

One method is to leach the sal skimmings with muriatic acid and to remove the insolubles, which include heavy metals formed by cementation with the metallic zinc. A liquor consisting of about 46 percent zinc chlor-

TABLE 12

THE PRODUCTION AND UTILIZATION OF BLAST-FURNACE SLAG IN 1957 (511)

Slag type	Slag processed (short tons)	Utilization
Screened air-cooled	25, 414, 327	92% used as railroad ballast, aggregate in portland-cement concrete construction, all types of bituminous construction, and miscellaneous highway and airport construction.
Unscreened air-cooled	2, 166, 678	61% used as aggregate in highway and airport construction.
Granulated	4, 318, 485	43% used as raw material in manufacture of hydraulic cement; 45% used in constructing base and insulating courses for highways and also as road fill; and 12% used in concrete-block manufacture and in agricultural and miscellaneous uses.
Expanded	2, 941, 650	Bulk used in manufacture of lightweight concrete blocks.

ide and 4 percent ammonium chloride is produced. Ammonia is added and zinc ammonium chloride is crystallized from the resulting solution. That product is sold for galvanizing flux.

SAND

See: References 34, 187, 360, 503.

SEAFOOD

See: Fish.

SHINGLES

See: Sanitary Landfill and Open Dumping.

SISAL

Wax is extracted from sisal wastes.[59]

SLAG

Large quantities of various types of slags have been processed and marketed by industry for a variety of uses. According to *Chemical and Engineering News* in 1959, from 30 to 35 million short tons of ferrous blast-furnace slag were being produced annually by the steel industry for eventual reuse.[550] *Pit and Quarry* stated that 35 million tons of blast-furnace slag valued at $52 million were produced in 1957.[511] Approximately 72 percent of this slag was processed by methods involving the separation of solid particles. According to *Blast Furnace and Steel Plant*, slag processors recovered 409,259 short tons of iron from blast-furnace slag in 1956.[549] In 1961 a British blast-furnace slag plant was turning out products for varied uses.[108]

Open-hearth slag has not been utilized as extensively as blast-furnace slag; its use has been largely experimental in nature. *Chemical and Engineering News* stated in 1959 that from 18 to 20 million short tons of open-hearth slag were being produced annually by the steel industry.[550] Of this amount, United States Steel alone produced 6 million short tons, but processed less than half of it for marketing.

Most of the blast-furnace slag produced has been utilized in the manner indicated in Table 12. It has also been employed: (1) in glass for the manufacture of amber bottles; (2) In fiberglass manufacture; (3) As a conditioner for oyster beds; and (4) As a conditioner for cranberry bogs.

Open-hearth slag has not been utilized as extensively as blast-furnace slag, but it has been used: (1) As an agricultural liming material and fertilizer; (2) as a soil supplement and conditioner; (3) as railroad ballast; (4) as highway chips; (5) as a sealing for highway surfaces; (6) as highway fill; (7) as an aggregate for the manufacture of bituminous concrete; (8) as a sand-blasting grit; and (9) as a source of trace elements.

The slag produced during the manufacture of elemental phosphorus has been utilized: (1) As a road-base material; (2) in septic-tank drain fields; (3) as a drainage stone in sewer lines; and (4) as a roofing aggregate.

See also: Recovery and Utilization; Foundry Wastes; Inorganic Residues; References 184, 403, 510.

CALCINATION

Slags have been calcined to produce cement, three types being produced. In 1939 there were 600,000 tons of blast-furnace slag alone used for this purpose.[54, 108, 511]

INCINERATION

Refractory ceramics have been made by burning slag.[116]

MAGNETIC SEPARATION, SCREENING, GRINDING

Open-hearth and blast-furnace slags have commonly been prepared for various markets by magnetic separation and screening. Magnetic separation has usually been employed for the recovery of tramp-iron, scrap and primary ferrous metal. Screening has often been used to size the slag itself into fractions suitable for various uses.

Trauffer has described the process employed at one Detroit plant for treating 110 tons per hour of blast-furnace slag by means of magnetic separation and screening to produce eight fractions of sized slag.[455] And Peck has described a similar but smaller operation which produces six sizes of screened blast-furnace slag at a rate that varies from 300 to 350 tons per hour.[343] The sizing of both blast-furnace and open-hearth slag at a single plant has been described by Utley.[489] *Rock Products* briefly mentioned how one plant sized phorphorus slag at the rate of 700 tons per day.[384]

Trauffer[454] has also described the production of sized agricultural slag from basic open-hearth slag by means of magnetic separation and screening.

The Birmingham Slag Division of the Vulcan Materials Company at Wylam, Alabama, has processed basic open-hearth slag produced at Birmingham and stockpiled at Wylam

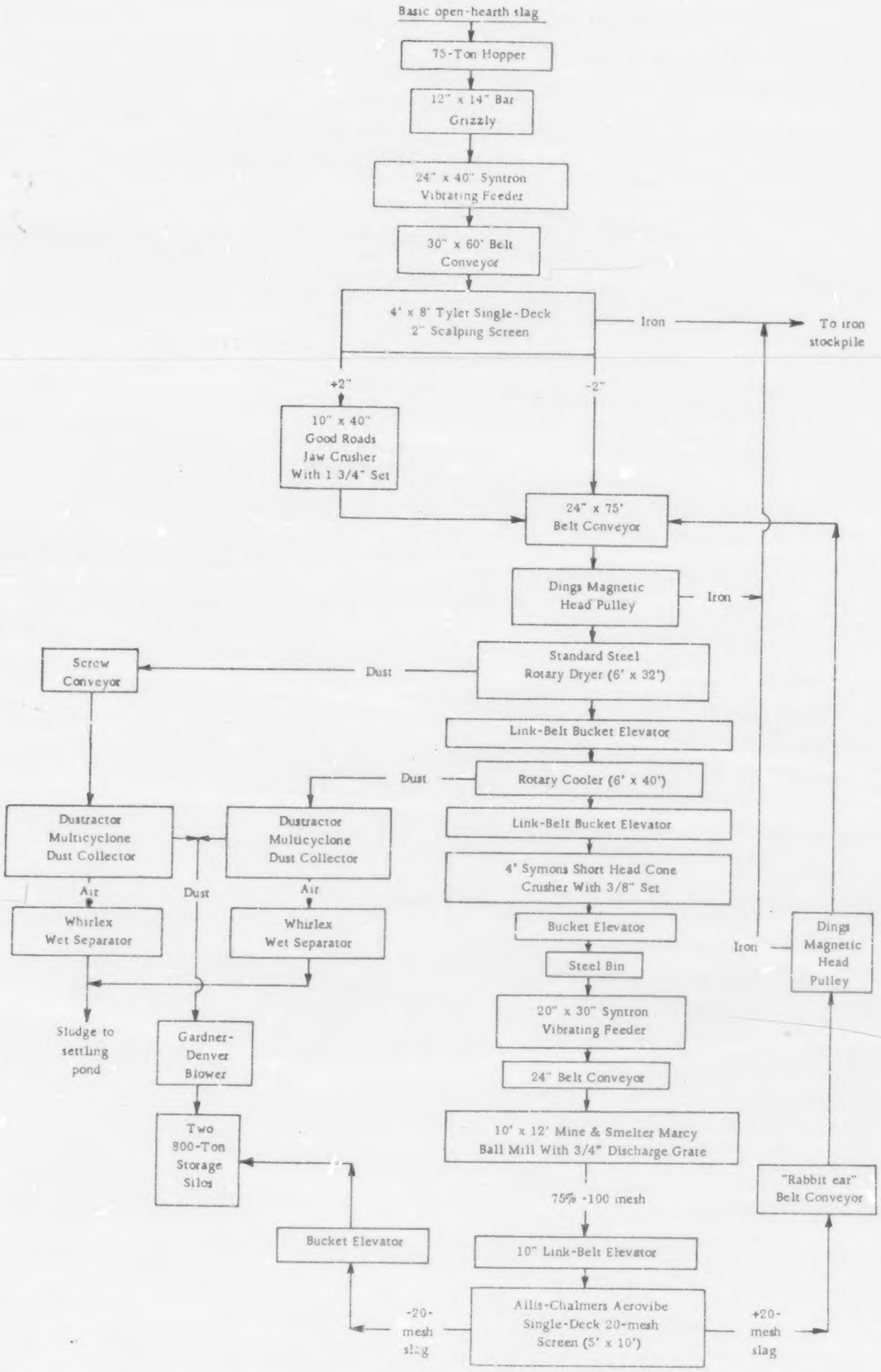
Basic open-hearth slag
75-Ton Hopper
12" x 14" Bar Grizzly
24" x 40" Syntron Vibrating Feeder
30" x 60' Belt Conveyor
4' x 8' Tyler Single-Deck 2" Scalping Screen
Iron
To iron stockpile
+2"
-2"
10" x 40" Good Roads Jaw Crusher With 1 3/4" Set
24" x 75' Belt Conveyor
Dings Magnetic Head Pulley
Iron
Standard Steel Rotary Dryer (6' x 32')
Dust
Screw Conveyor
Link-Belt Bucket Elevator
Rotary Cooler (6' x 40')
Dust
Link-Belt Bucket Elevator
Dustractor Multicyclone Dust Collector
Dustractor Multicyclone Dust Collector
Air
Dust
Air
Whirlex Wet Separator
Whirlex Wet Separator
Sludge to settling pond
Gardner-Denver Blower
Two 800-Ton Storage Silos
4' Symons Short Head Cone Crusher With 3/8" Set
Bucket Elevator
Steel Bin
Iron
Dings Magnetic Head Pulley
20" x 30" Syntron Vibrating Feeder
24" Belt Conveyor
10' x 12' Mine & Smelter Marcy Ball Mill With 3/4" Discharge Grate
75% -100 mesh
"Rabbit ear" Belt Conveyor
Bucket Elevator
10" Link-Belt Elevator
Allis-Chalmers Aerovibe Single-Deck 20-mesh Screen (5' x 10')
-20-mesh slag
+20-mesh slag

FIGURE 7. *Processing of U.S. Steel basic open-hearth slag at Wylam, Alabama.*

by the United States Steel Corporation. Slag ranging in size up to 12- to 15-inch chunks has been treated in this plant at the rate of 60 tons per hour by the process illustrated in Figure 7. Large pieces of slag held up by the bar grizzly are sledged through it to the vibrating feeder. Each of the Dustractor dust-collecting systems employed has a capacity of 28,000 cubic feet per minute. The Marcy ball-mill grinds an average of 60 tons of slag per hour to at least 75 percent minus 100 mesh. It has a 4-inch manganese steel lining and is charged with 60 tons of United States Steel high-carbon-steel grinding balls ranging in diameter from 1 to 4 inches. The belt conveyor employed to recycle the plus 20-mesh slag is equipped with a Dings magnetic head pulley, which removes any remaining iron and any undersize grinding balls that may pass through the mill grate. The entire mill circuit is connected to a 10,000-cubic-foot-per-minute Pangborn bag-type dust collection, which discharges to the screw conveyor that reclaims processed slag from the storage silos. This processed slag has been sold at USS Basic Slag for use as a soil conditioner.

SODIUM

See: Reference 123.

STARCH

Gluten, the principal by-product of the starch industry, can be obtained by evaporating steep water. It is used for feed.[464]

STONE SPALLS

Boynton has pointed out that in most limestone-processing operations there are large tonnages of stone sizes that cannot be used or sold, at least without further processing and classification.[57] These "spalls" may accumulate to the extent that they constitute a storage problem. Since the cost of producing such waste stone has already been absorbed, the waste may have no value, or even a negative value. Through research and reprocessing, it is often possible to obtain salable products from such wastes by grinding and screening at low cost, often at costs appreciably lower than costs of other producers manufacturing the same gradation as a prime product. The market may then become sated, and prices badly depressed, and the prime producer may lose both volume and profit. Such by-product-stone sources may be only temporary, disappearing in a year or two after the spalls are exhausted. But the unpredictable availability of such byproducts and the sporadic losses it causes is a serious problem to the prime manufacturer. The constant threat of such competition serves as a depressant on stone prices.

Similarly, a large captive stone producer, typified by the lime, steel, alumina, alkali, and other industries, processes stone primarily for its own use as kiln feed, flux stone, raw material, etc. The cost of producing this stone is absorbed by the end product. Therefore, the sizes that cannot be consumed are regarded as waste. Any monetary return from the sale of such stone is applied to reducing the overall cost of the end product. Converting such stone to marketable products enables the captive plant to sell at a lower price than the prime stone producer can. Often such stone is not merchandised, but is sold or "dumped" at unreasonably low prices. Subsequently, prices of such by-products may be raised to a reasonable level, but meanwhile, dumping has a damaging effect upon competition. In many areas, by-product stone determines the price for all similar prime stone.

SUGAR BEETS

Lime sludge from beet sugar mills has been reburned in a fluidized-bed reactor and recycled to the process.[260] Lime sludges from beet-sugar mills can be used as fertilizer for low-pH soils.[373]

SUGAR CANE

See: Bagasse.

SULFUR

Sulfur-refining wastes have been burned in a fluidized bed.[77]

TANTALUM

See: Reference 145.

TETRAETHYLLEAD

Sludges resulting from the manufacture of tetraethyllead are prepared for recovery of lead in the furnace by compressing and pelletizing them under pressure[103]

TEXTILES

The major categories of solid textile wastes have included cotton and cotton linters, woolen scrap and rags, woolen noils, scraps from silk, hemp, flax, rayon, and other synthetic materials. These are recovered and reprocessed to yield lanolin, sugar, paper, furfural, fiberboard, and adhesives.

See also: Recovery and Utilization; Cotton; Reference 333.

CARBONIZATION

The vegetable-fiber content of woolen rags has been treated with gaseous HCl and the carbonized fibers are removed, after which the material is reused.[263]

EXTRACTION

Wool and linen waste, jute waste, and rayon waste have been extracted with an organic solvent to recover wool grease.[51]

HYDROLYSIS

Hydrolysis with hydrochloric acid of cotton linters yields sugar.[346] Cotton linters mixed with sulfuric acid make an adhesive paste.[496] Carding wastes have been processed by hydrolysis to produce cigarette paper.[248] Furfural has been obtained by hydrolysis of linen and flax wastes.[223, 350, 416] Rayon-pulp-mill rejects have been digested and heated and formed into fiberboard.[493]

TIN

During World War II tin cans were collected for the purpose of recovering the tin. Collection of the cans was costly, and processes for tin recovery were not successful. However, this in no way detracted from the success of the initial hand-sorting operations performed at the source.

See also: Recovery and Utilization.

TITANIUM

A processing method employed to prepare titanium chips for marketing has been described in an article appearing in *Steel*.[145] The article states that turnings of titanium that arrive at the plant, in lots ranging from a few hundred pounds to many tons, are usually contaminated with other alloys and with cutting oils. Each lot must be identified and crushed. Trained workers hand-sort the pieces and use a series of chemical and electrothermal tests to determine alloy types and metal contents. After the chips are identified and crushed, they are thoroughly cleaned in a vibrating degreaser to remove all traces of cutting oil, greases, and fines. Other contaminating metal particles, such as tool bits, are removed by special magnetic equipment as the chips are conveyed to an electronic checker, where they are visually inspected before packaging. The production of zirconium, tungsten alloys, molybdenum, columbium and tantalum from scrap is covered in the *Steel* article.

In *Iron Age* a new furnace that permits recovery of titanium scrap is described.[547]

CALCINATION

Pure gypsum can be obtained by calcining waste sludge from TiO_2 manufacture.[190]

ELECTROLYSIS

The production of high-purity titanium by electrolysis from scrap has been discussed.[357]

EXTRACTION

Titanium oxide can be recovered from solid wastes from titanium production by leaching and chlorinating to oxidize iron.[121]

MELTING

Waste sand from titanium mineral processing can be made into a refractory by melting it with bauxite in a resistance-arc furnace.[457]

RECRYSTALLIZATION

The gypsum obtaned by neutralizing the waste acid from TiO_2 manufactured with limestone can be calcined and then recrystallized. The properties of recrystallized gypsum have been given.[330]

TOBACCO

See: Reference 230.

TUNGSTEN

See: References 61, 145.

URANIUM

Jasmy reported on a process for recovering uranium from unirradiated fuel-element scrap.[213] Techniques were described for dissolving uranium-stainless steel in nitric acid, uranium-zirconium alloy in hydrofluoric and nitric acids, and uranium-aluminum alloy in sodium hydroxide and sodium nitrate. The scrap is received as billets, turnings, strips, and fines. Uranium has been recovered from the solutions of dibutyl carbitol extraction, with 99.9 percent overall efficiency. The uranium can be stripped from the carbitol with nitric acid to yield pure uranyl nitrate.

See also: Separation.

VANADIUM

Vanadium is recovered from the production of aluminum oxide by extraction.[468]

VEGETABLE WASTES

See also: Agricultural Wastes; Bagasse; Food-Processing Wastes; References 103, 331, 513.

EXTRACTION

Pectin can be extracted from potat pulp.[168] Hemicellulose esters have been extracted from lima-bean pods and corn cobs.[484] Protoplasts can be extracted from leafy wastes as chlorophyll derivatives for industrial and pharmaceutical use.[484]

HYDROLYSIS

The sugar in green-pea hulls can be hydrolyzed under pressure in sulfuric acid and Torula utilis grown on the sugars produced.[444] Torula utilis can also be grown on hydrolyzates of reed grass refuse.[400] Butanol and acetone are produced from sugars from corn cobs and other vegetable waste products.[315] The hydrolyzates of sawdust, sunflower wastes, cereal straw, and the hulls, grits, and other wastes of barley and millet milling have been fermented to produce yeast.[47, 112, 194] Plant residues have been subjected to hydrolysis to obtain cellulose for use in the manufacture of paper and board. Agricultural residues,[23, 46, 252, 400] tobacco wastes,[114, 230] banana stems, areca stalks,[437] corn stalks,[285] jute sticks,[169, 299] the woody part of hemp,[14] esparto grass,[270] straw,[398] and bagasse,[19, 21, 22, 24, 42, 55, 75, 88–90, 107, 146, 171, 192–201, 226, 262, 283, 286, 281, 290, 301, 326, 401, 411, 486, 528, 539] have all been used for this purpose. A continuous process has been developed to prepare pulp from plant residues.[299] Plastic can be obtained from plant wastes by hydrolysis.[331]

PYROLYSIS

Fuels and solvents have been manufactured by pyrolysis of waste products from the fat and vegetable-oil industries.[396]

WASTEPAPER

The reuse of wastepaper products is a growing industry. Much effort is currently devoted to improving practices and cutting costs not only by the various individual companies, but also by the research activities of the organizations to which the companies belong, among which are the Boxboard Research and Developments Association, the Waste Paper Institute, and the Technical Association of the Pulp and Paper Industry.

Wastepaper that can be reused encompasses almost every type of paper manufactured. According to the Waste Paper Institute, some 40 grades are recognized. Most of these grades refer, however, to paper types that can be classified as: (1) mixed paper, kraft wrapping, old corrugated containers, etc., from industrial concerns, department stores, etc., (2) old newspapers and magazines collected from private homes or over-issues from publishers, (3) waste from printers, envelope manufacturers, etc., and (4) cuttings from box and bag manufacturers.

The contamination of such paper with polystyrenes and polyethylenes, asphalt papers, carbon paper, and plastic-coated paper has presented difficulties and no means were found reported for their economic separation. However, Kobor has described a means of removing synthetic resin contaminants by hydrolysis.[235]

Since the market value of wastepaper products has varied widely, the collection and treatment of it has been somewhat risky. The approproximate prices paid per ton in November 1966 for various types of reusable wastepaper products were as follows: overissue news, $25; No. 1 news, $18; old corrugated, $22; white ledger, $50; books, $20; and manila tab cards, $85. Sorting increases the value of wastepaper products, but it is expensive. From one half to 7 man-hours are required to sort a ton of such material. Considerable quantities of wastepaper have been collected by charitable organizations and fed back into the paper industry; this paper is hand sorted at the home level. However, when this material has been mixed with other trash and hauled to a central disposal point, its segregation and reuse has been virtually impossible.

Charitable groups utilizing volunteer labor have been about the only organizations that can afford to collect newspapers, magazines, etc., from private homes. Wastepaper dealers, on the other hand, have been able to profitably handle overissue news, containers, cuttings, etc. from manufacturers, since the cost incurred in their disposal is often included in that of their production. Contaminants must first be sorted from any waste groundwood or pulp paper products destined for use in the manufacture of the best quality paper. The reuse of wastepaper has been comparatively common in Europe where pulp wood has been in short supply and where paper products of a relatively low grade are utilized.

It is probable that almost every boxboard plant (2,300 in the United States) uses waste in one form or another, the majority employing only mechanical disintegration. It has been estimated that more than 30 plants employ deinking operations with an annual capacity over 500,000 tons.

See also: References 16, 397.

JUNK REMOVAL

Since few paper mills sort their wastepaper before it is deinked, the stock that many of them treat for fiber reclamation is often contaminated with waste materials other than ink. The removal of these contaminants frequently involves the removal of miscellaneous waste materials such as dirt, cellophane, wet-strength paper, adhesive tape, binding cement, heat-seal label scraps, rubber bands, paper clips, staples, plastics, baling wire, rags, string, gummed tapes, and pins. Material such as this must be eliminated from the pulped paper fiber before deinking to protect the papermaking equipment and to insure the proper quality and uniformity of the finished paper product.

Junk removal is often achieved by screening, centrifugal separation, magnetic separation, or mechanical sorting. The junk encountered in most wastepaper is of such a variety that both screening and cycloning are required to remove it. While the removal of junk from pulped paper is frequently employed in conjunction with deinking operations, it is not considered an inherent part of the deinking process itself.

Brown refers to the removal of foreign matter from pulped fiber by means of screening, magnetic separation, and centrifugal separation.[90] Large pieces of such material can be removed by perforated plates if they are not broken up during the pulping of the fiber. Metallic objects of iron such as paper clips and staples are frequently removed by magnetic separators.

McKela has described several pieces of equipment that are utilized in the removal of junk from pulped wastepaper.[250] The ragger and bucket elevator or junk remover are commonly employed to clean the pulped fiber produced by the Hydrapulper. These devices operate efficiently with minimum fiber loss when treating Hydrapulper consistencies that range from 1.5 to 2.5 percent. In this consistency range, the ragger and junk remover are most efficient in the removal of baling wire, rags, string, gummed tapes, wet-strength papers, etc., and bottle caps, wood, beer cans, glass, nuts and bolts, etc., respectively. The ragger consists of a double-serrated sheave with an adjustable, weighted wheel that holds the rag or rope in place. Power is supplied to the device by a small, variable-speed motor that governs the rate at which the rope is withdrawn from the Hydrapulper tub. The action involved in the separation of materials by the ragger can be described as a form of mechanical sorting.

See also: Separation.

DEINKING

If separation of ink and dirt from paper is required, screening or flotation is usually done after the waste has been mechanically hydrapulped with chemicals to free contaminants from the fibers. Chemicals commonly used to loosen ink are sodium silicate, sodium peroxide, soda ash, soap, detergents, and phosphates. Hydrapulping is normally done at 120° to 160° F. for an hour or more. Consistencies may be as low as 4 percent or as high as 25 percent, depending upon the system employed.

After hydrapulping and cooking, the pulp, at less than 1 percent consistency, is passed over various types of screens to remove coarse impurities, and probably through cyclone-type devices for removal of heavy dirt and metallics. The pulp is then ready for deinking by either flotation or screening (washing).

In the screening-washing type of cleaning, the operation is performed on multistage washing cylinders covered with wire of about 65 mesh. Copious amounts of wash water are required to remove the carbon, fillers, etc. Fiber recovery of 85 percent may be anticipated with a chemical cost of $10 to $15 per ton. Generally speaking, the higher the chemical consumption, the brighter the recovered stock.

See also: Reference 324.

FLOTATION

Flotation may also be used to remove the contaminants from wastepaper treated in secondary reclamation systems. After proper preparation with chemicals the pulp is treated in flotation machines, and the contaminants removed as a froth or scum. Two typical formulations are shown in Table 13.

TABLE 13

TYPICAL FORMULATIONS USED WITH FLOTATION MACHINES

I	II
0.8% triton X-100	1.5% Na_2O_2
2.0% tripolyphosphate	3.75% Na_2SiO_3.
1.7% soft soap	3.0% soap.
1.3% $CaCl_2$	$CaCl_2$ to produce equivalent $CaCO_3$-hardness of 215 ppm.
Cook in Hydrapulper 30 min at 120 F	Cook in Hydrapulper 30 min at 120 F.
Float 3–5 min at 0.8% consistency	Float 3–5 min at 0.8% consistency.

Recent developments have indicated that polystyrene and polyethylene materials may also be removed by flotation.

The cost for flotation machines for a 50- to 100-ton-per-day plant would be approximately $50,000 to $75,000, depending on the time of float. Only one operator would be required per shift. The primary cost item in processing is that of chemicals and may be from $10 to $15 per ton of paper. Labor, maintenance, and power should not exceed $1.00 per ton. A fiber recovery of 90 percent may be expected.

After the impurities are separated, bleaching may be used to whiten the stock before it is prepared for use by further washing and thickening.

See also: Separation.

MECHANICAL DISINTEGRATION

Another method of wastepaper processing is simple mechanical disintegration in an agitator, such as the Hydrapulper manufactured by the Black Clawson Company, until the fiber has been beaten up to the desired fineness. A similar machine is the Wet Pulper, manufactured by the French Oil Mill Company. Material so processed can be utilized as a filler in the manufacture of boxboard, matches, and other low-grade products where color and/or specks are not objectionable and where bulk is the primary requirement.

See also: Separation.

SCREENING

Kleinau has described the process utilized by the Bergstrom Paper Company of Neenah, Wisconsin, for the

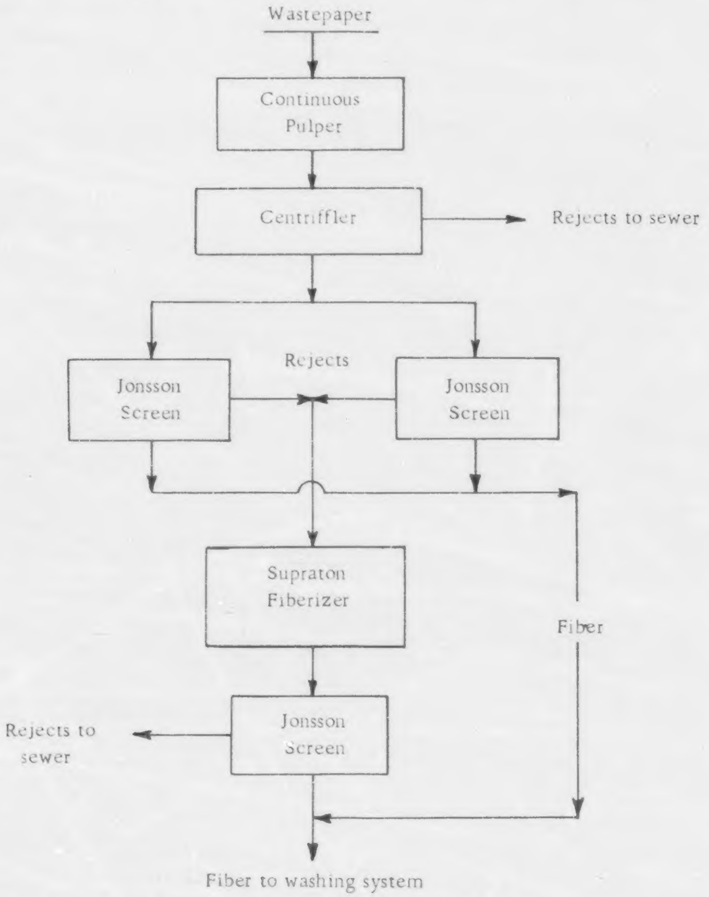

FIGURE 8. *The deinking of secondary paper fiber by screening.*

deinking of secondary paper fiber by screening.[232] The process, illustrated in Figure 8, has been employed primarily for deinking pulped secondary paper fiber, but contaminants such as plastic and rubber can also be eliminated. The entire stock of pulped paper is first passed over only two Jonsson screens at a flow rate above that of their normal screening capacity. This is done to assure a high rate of reject flow to the subsequent defibering operation. The fiber bundles and ink of the reject pulp are then broken up in a defibering machine known as a Supraton fiberizer. A third Jonsson screen is finally employed to separate the reject material from the clean paper fiber of the defiberized pulp. The cleaned stock produced by the three screens is subsequently transferred to the pulp-washing system, while the reject material is discharged to sewers.

In this operation, the fiberizer treats a pulp consistency of slightly under 3 percent at a throughput of 12 tons per day of stock, a flow rate equivalent to about 7 percent of the total. The fiberizer utilized has been supplied with a 75-horsepower motor, but used only 25 horsepower at a rate of 2.1 horsepower-day per ton. This fiberizer was unique in that it facilitates the screening of extraneous material, such as rubber and plastic, from the paper fiber by permitting them to pass unchanged through the defibering operation.

Lehman has considered the general application of various types of screens to the cleaning of waste paper in deinking systems.[257] Screens have been employed in these systems primarily to remove nonferrous materials of low specific gravity.

Multistage screening systems have been employed by many mills in an effort to derive the maximum benefit from their fine screens. The coarse screens utilized in these systems must have large holes and a high capacity per unit to remove large particles. The vibrating-deck screen has been most commonly used for this purpose, but flat screens, rotary-type screens, and pressure screens can be employed as well.

Most of the fine screens in use have been designed to use fine-slotted plates. The types most frequently encountered are the flat screen and the rotary-vibratory screen. Fine screens with round holes have, however, proved to be much better. Pressure screens and centrifugal screens are types of round-holed screens that should be strongly considered in any new or revised screen layout. Vertical pressure screens have come close to being the ideal fine screens, as they operate in a closed system that is both clean and quiet.

Reject or tailing screens have been employed in the multistage systems because fine screens do not function efficiently without rejecting good fiber with waste material. Flat and vibrating-deck screens are the only types of screens capable of achieving the clean separation of fiber and fiber-free waste.

See also: Separation.

CYCLONES

The general application of cyclones to systems involved in the deinking of secondary paper fiber has been reviewed by Fahlgren.[131] Cyclones employed in the pulp and paper industry have ranged in size from 3 to 48 inches in diameter, and in throughput from less than 20 to as much as 6,000 gallons per minute respectively. Large-volume cyclones have largely replaced the space-consuming riffler for the removal of dirt from pulped paper fiber. Separations achieved with them have been far superior to that achieved by the riffler, at both high and low stock consistencies.

Large cyclones are usually employed after pulping and prior to screening for the removal of junk such as bottle caps, paper clips, tramp iron, rocks, and coarse sand. The following types of cyclones are suitable for the removal of such material: (1) large-volume cyclones operating at relatively low consistencies, (2) large-volume cyclones capable of handling high-consistency stocks, and (3) relatively low-volume cyclones capable of operating at consistencies as high as 6½ percent air dry.

The smaller cyclones, ranging in diameter from 3 to 12 inches, have been widely employed for the removal of shives and specks from low-density stocks. Installations of these cyclones have been either single or multistage, the primary units often being equipped with a secondary unit. These units are efficient dirt removers and operate with a minimum loss of fiber. The maximum cleaning efficiency has been provided, however, by a multistage installation involving the dilution and recirculation of fiber pulp between stages. The rejects from the primary cyclones usually contain good, usable fibers that can subsequently be recovered in second, third, or fourth stages. Small cyclones operate according to the following principles as given by Fahlgren[131]: (1) The smaller the cyclone diameter, the more efficient the removal of specks and fine dirt particles; (2) the larger the diameter, the longer the shive that can be removed; (3) the higher the efficiency of speck removal, the higher the concentration of short fibers; (4) for the smaller diameter units, consistency of 0.5 percent is most effective; for larger diameter units, 0.7 percent is considered economical and efficient; (5) secondary and following stages should operate at lower consistencies than the primary stage; (6) reject rate is controlled by the back pressure and the size of the reject opening; and (7) the back pressure should be kept con- the back pressure should be kept constant for maximum cleaning efficiency.

The size and number of cyclones required for a given operation may be determined by the character of the furnish, the character and amount of foreign particles to be removed, and the volume of the stock to be handled. A high-capacity, high-efficiency, primary cyclone can be used for the removal of low- and medium-specific-gravity materials (such as glass and sand), which often pass through the perforations of the Hydrapulper with the stock flow. This device is equipped with conical ceramic inserts that have proven to last longer than those of alloy steel.

See also: Separation.

WOOD WASTES

Wood wastes start in the forest where only about 81 percent of the tree is removed as sawlog, in the lumber mills where 16 percent is wasted as sawdust and 34 percent as slabs and edging, and in the paper mills where about 50 percent of the log is discharged in waste effluents or is disposed of by burning. Wood wastes can be processed to recover a variety of by-products, but these processes have been applied to only a small extent.

Lignin, the main noncellulosic constituent of wood, can be processed to obtain valuable chemicals, such as pure lignin and dimethyl sulfide. It can also be utilized without processing as a binder, a dispersant, an emulsion stabilizer, and a sequestrant.

The hemicellulose or polysaccharide portion of the wood is readily hydrolyzed into simple sugars. In the sulfite process, about 300 to 400 pounds of hemicellulose have been converted into sugar for each ton of sulfite pulp produced. Although processes for utilizing these sugars are technically feasible, the economics have been unfavorable. Studies in Canada have shown that the minimum economical size for a plant to produce alcohol would produce 1½ times the national consumption of alcohol. Fodder yeasts and organic chemicals such as furfural are important products of sugars from hemicelluloses, and the market for these materials could grow.

Sawmill wastes can be utilized by the pulp industry to a large extent. Several mills in Canada have formed cooperatives and purchased the equipment needed to bark and chip wood wastes to make them suitable for pulping. Waste bark and mill waste have also been sent to companies that make wallboard and roofing felts.

The proximity of a healthy petrochemical industry on this continent has kept the pace of chemical utilization of forest products considerably behind that of the Scandinavian countries, since many wood chemicals are competitive with petroleum chemicals. Experimental work is being done in this country to make a lignin-type plastic from wood waste.

See also: References 202, 436, 442, 456.

ACIDIFICATION

A pasty coal igniter has been prepared by treating a mixture of peat, sawdust, and cellulose wastes with acid and wetting the product with sulfur in gasoline.[434] Cellulose, oxalic acid, acetic acid, vanillin, tannin, etc., are recovered from wood and vegetable waste in an apparatus specially designed for continuous recirculation of nitric acid through the waste.[103]

CARBONIZATION

The activity of carbons from sawdust in relation to the activation process has been described.[231, 458] Dry distillation of sawdust was reported to yield activated carbon of high grade.[290]

CONDENSATION

Lignocellulosic wastes have been condensed with sulfur compounds and digested with water at high temperature to produce plastic material suitable for pressing into boards.[317]

DEHYDRATION

Charcoal of high discoloration power can be obtained from sawdust by dehydration with sulfuric acid.[73]

EXTRACTION

Extractives, the noncellulosic portion of wood extractable by neutral solvents, include a number of potentially valuable organic chemicals. An adhesive that is cold-setting and waterproof has been called one of the most promising extract products.

Wood wastes can be extracted with gasoline [153] and methyl alcohol [232] to obtain rosin.

GRAVITY SEPARATION

The application of gravity separation to the recovery of waste wood produced in the pulp and paper industry has been described by Wesner.[478, 479]

HYDROLYSIS

The conversion of wood cellulose to fermentable sugars has been the subject of numerous investigations.[52, 90, 120, 158, 211, 221, 238-240, 246, 275, 282, 302, 327, 341, 415, 416, 504] Yeast containing 25 percent fat has been grown in these sugars.[428] Alcohol has been distilled from the fermented wood sugars.[185, 408] White wine can be obtained by refluxing sawdust with sulfuric acid.[565] The glucose obtained from lumber and pulp-mill leftovers can be concerted to levulinic acid and formic acid.[182] Wood as a chemical raw material has been discussed by Wenzel.[477] Furfural is an important product of wood hydrolysis.[218, 221, 223, 327, 350, 468] Many authors report on the use of wood wastes in the manufacture of paper board.[160, 176, 193, 208, 210, 221, 440, 441, 494, 542, 556] The influence of bark on the properties of pulp has been described.[353, 388]

See also: References 104, 328.

INCINERATION

Wood residue has been incinerated in tepee waste burners with some degree of air pollution—low enough to be acceptable in some areas.[56] Wood waste has been used for fuel in a large water tube boiler.[398] The products of combustion of wood wastes can be used to produce ammonia.[377]

See also: References 354, 533.

OXIDATION

Oxidation and hydrolysis under pressure followed by hydrogenation has appeared to be a possibility for the preparation of various petroleum chemicals from wood wastes and agricultural residues.[477]

Fertilizer can be prepared from sawdust or wood chips by first oxidizing the material with nitrogen dioxide and then adding ammonia to increase the nitrogen content.[142] Mellitic acid and other polycarboxylic acids can be obtained by nitric acid oxidation of sawdust.[147] Sawdust has been added to kilns to reduce iron in the production of ferronickel from nickel ores.[90] Oxidation of lignin waste and sawdust with either phenol nitrate or copper oxide yields vanillin.[164, 165]

SCREENING

The application of screening to the sizing of bark was mentioned by Pierce and Sproull in their description of a process involving the conversion of bark to plant food.[349] The production of plant food and soil-amendment products from southern pine bark by the Greenlife Products Division of The Chesapeake Corporation of Virginia was the first commercial application of this process (United States Patent 2, 881,066). In the process, bark is first ground and then screened into various size fractions. Selected size fractions are subsequently steamed at a temperature above 170° F. and impregnated while hot with solutions of various nutrients. After the bark has been impregnated, it is dried and bagged. Information concerning process costs and equipment has not been available.

See also: Separation.

PYROLYSIS

Dry distillation of sawdust and wood wastes yields activated carbon of high grade together with methanol, acetic acid, acetone and wood tar as by-products.[200, 456] high temperature and catalytic cracking during pyrolysis of sawdust produces an equimolar mixture of hydrogen and carbon monoxide.[433] The heat values of the fuel gas obtained have been given.[115] Sawdust can be decomposed in a fluidized bed.[115, 242, 495] Thermal decomposition of wood in aqueous medium under pressure resulted in larger amounts of chemicals than destructive distillation.[241] After recovery of products obtained by heating sawdust soaked in kerosene at temperatures below 275° F., the temperature is raised, the kerosene is distilled, and the residue is used as a fuel.[417] While the pyrolysis of wood to produce acetic acid and methanol was in past years a substantial industry, it has largely been supplanted by synthetic methods. However, recently about 20 million pounds of acetic acid a year and 14 million pounds of methanol a year was being produced by the old process.[182]

VAC-SINK PROCESS

The Vac-Sink Process was developed for recovery of the wood fraction from waste products.[478, 479] The separation is based upon the inducement of a gravity differential between the wood and the bark. After the bark has been freed from the wood with a chipper, the mixture is immersed in water and a vacuum is applied. Entrained air is easily withdrawn from the continuous and interconnected passages of the wood but not from the collapsed passages of the bark. The release of the vacuum causes water to enter the vascular passages of the wood formerly occupied by air. The heavy combination of wood and water quickly sinks away from the lighter combination of bark and air that remains at the water surface. Wood recoveries of over 90 percent are usually achieved in wood-bark separations such as this.

The Vac-Sink process was first employed on a commercial scale at the Savannah, Georgia, mill of the Union Bag-Camp Paper Corporation. This plant can process waste wood at a capacity equivalent to 100,000 cords of wood per year. The wood recovered by the plant can subsequently be processed to make paper, the bark being utilized as a fuel. Cost data and information concerning the equipment employed in the plant have not been available.

See also: Agricultural Wastes; Pulp and Paper; Sanitary Landfill and Open Dumping.

WOOL

See: Textiles; Reference 421.

YTTRIUM

Provow and Fisher published a paper describing a process for reclaiming yttrium scrap by chemical procedures.[367] According to these authors, yttrium can be recovered from wastes by burning the wastes and dissolving the residue in nitric acid. The impurities can be removed by precipitation, the yttrium then being precipitated with oxalic acid.

Provow and Fisher have also described a low-cost process that uses readily available chemical reagents and equipment to reclaim yttrium from scrap in the form of small pieces, turnings, and saw filings.[357] The scrap is converted to crude oxide by ignition. One-hundred-pound batches of the minus 80-mesh oxide are dissolved in 50 percent nitric acid. The resulting solution is purified by hydrolysis of zirconium, iron, aluminum, and titanium. Then potassium ferrocyanide is added to precipitate copper and nickel. The yttrium is precipitated as oxalate with oxalic acid, after which the filtered and washed precipitate is ignited to produce the oxide. The chemical costs of a large-scale operation were reported as $0.67 per pound of yttrium oxide.

See also: Nonferrous Scrap.

ZINC

See also: Lead; Pyrite Cinders and Tailings; Sal Skimmings.

EXTRACTION

Weak hydrochloric acid has been used to leach zinc from waste materials.[313] Cadmium is extracted from the residue of zinc refining with sulfuric acid. The acid solution is electrolyzed to recover cadmium.[340]

GRAVITY SEPARATION

Phillips briefly mentioned the application of gravity separation to the recovery of zinc from contaminated crusts of zinc and zinc oxide in zinc-smelting operations.[347] These crusts form on the fireclay condensers utilized in the reduction of zinc in horizontal retorts. The spent condensers have usually been crushed to produce metal-bearing refractory particles which have subsequently been treated in jigs and on shaking tables to produce a concentrate containing from 60 to 70 percent zinc and from 60 to 80 percent of the condenser zinc. This concentrate can eventually be recycled to the retorts. Heavy-medium separation has been applied in one plant to recover metallic zinc from electrothermic zinc residues.

See also: Separation.

HYDROMETALLURGICAL PROCESSING

Zinc metal has been produced from zinc oxide in retort or electrolytic reduction plants operated mainly for the production of primary zinc. The preferred method for reduction of zinc oxide has been the electrolytic process. The procedure in one plant treating zinc oxide fume alone has been as described below.

The fume contained about 77 percent zinc, about 1 percent each of lead and iron, and less than 0.1 percent each of germanium, cobalt, and copper. It was ground in airswept ball mills to about 70 percent minus 325 mesh and leached batchwise with the sulfuric acid in spent electrolyte from the deposition process. The resulting neutral liquor of zinc sulfate was filtered to remove iron and lead, and the filtrate purified. Purification was accomplished by stirring copper sulfate, arsenious oxide, and zinc dust into the liquor. That treatment removed and reclaimed germanium, copper, and cobalt.

The purified zinc sulfate liquor was electrolyzed in the conventional manner with anodes of lead alloy and aluminum cathodes. The deposition of zinc was accompanied by the formation of sulfuric acid in the so-called "spent electrolyte". That acid liquor was used to leach more fume. The zinc sheets deposited by electrolysis were stripped from the cathodes, washed and melted. The molten zinc was cast into slabs of "Special High Grade" quality.

ZIRCALOY

Rubin and Gessner have described the use of magnetic separation and screening in the recovery of Zircaloy scrap at atomic-power facilities.[384] Chips produced during the machining of hot-rolled Zircaloy strip are first crushed in a hammermill. The crushed material is then conveyed over strong magnets to remove magnetic contaminants and is finally sized on a 20-mesh screen to eliminate fine particles. The cleaned Zircaloy is subsequently melted into ingots for later reuse.

ZIRCONIUM

See: Nonferrous Scrap; Reference 145.

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